LECTURES

ON THE

ERRORS OF REFRACTION

AND THEIR

CORRECTION WITH GLASSES

DELIVERED AT THE

NEW YORK POST-GRADUATE MEDICAL SCHOOL

WITH

ILLUSTRATIVE CASES FROM PRACTICE, BOTH PRIVATE AND CLINICAL

BY

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TO

D. B. ST. JOHN ROOSA, M.D., LL.D.

PROFESSOR OF DISEASES OF THE EYE AND EAR IN THE NEW YORK POST-GRADUATE
MEDICAL SCHOOL AND HOSPITAL, AND PRESIDENT OF THE FACULTY,
MY TEACHER AT THE UNIVERSITY OF THE CITY OF NEW
YORK, AND CONSTANT ADVISER SINCE THEN

AND TO

WILLIAM H. FOX, M.D.

WASHINGTON, D. C.
MY BELOVED FRIEND AND ASSISTANT

THIS WORK IS DEDICATED

IN RESPECTFUL ADMIRATION OF THEIR WORK AS

PHYSICIANS AND SURGEONS

PREFACE.

These lectures to the physicians who attended the section on Diseases of the Eye, at the New York Post-Graduate School, having been received by them with many words of approval, and also with the request that I would publish them, are my reasons for now offering this work upon the "Errors of Refraction" to the profession. I know that many text-books treat this subject in perhaps a more scientific manner than it is here presented, but I have endeavored to make this work as simple and practical as possible.

The methods of testing for and prescribing glasses, as herein described, are so simple that they can be readily understood even by one who is not familiar with the science of ophthalmology; and are so written that they will be of service in the hands of the general practitioner, who has too little time to devote to the study of the larger works on Refraction.

I believe that there are some subjects which I have discussed that will also be of value to the specialist, in the work of correcting the errors of refraction; as in the lectures on retinoscopy and astigmatism, and in the diagnosis of refraction with the ophthalmoscope.

I am indebted to my friend and teacher, Prof. D. B. St. John Roosa, for many of the practical points in these lectures, and likewise for almost all my early teachings on this subject. I am also indebted to my kind friend, Dr. W. H. Fox (now of Washington, D. C.), who was with me during the years of 1886 and 1887 at the Post-Graduate

School, and from whom I received many valuable suggestions in regard to the refraction of the rays of light, as they pass to and from the retina of the human eye. It is with great pleasure that I thank these gentlemen for their ever ready assistance to me in the past, and for their kind advice and counsel in the preparation of this work.

I also acknowledge the assistance I have received from the books of Prof. E. Landolt, of Paris, and also to Gustavus Hartridge, F.R.C.S., England, whose works on Refraction I have studied with benefit to myself, and from which I have quoted in these lectures.

The illustrations and diagrams are many of them reproductions of the blackboard drawings that I have been accustomed to use in illustrating my lectures to the classes, and I am sure will be, in this connection, of service to the reader, in understanding the direction of the rays of light as they pass through, and are refracted by, the various media.

Repetition of many points and cases has been necessary in this work to make it clearly understood, and to impress the methods of examination on the reader; and while to the specialist they may seem very unnecessary, yet to the physician who is beginning the study of the errors of refraction I am sure they will be of service.

As a simple and at the same time complete method for the diagnosis and correction of all the errors of refraction, I offer this monograph to the general profession.

New York, 1888.

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ILLUSTRATIONS AND DIAGRAMS.

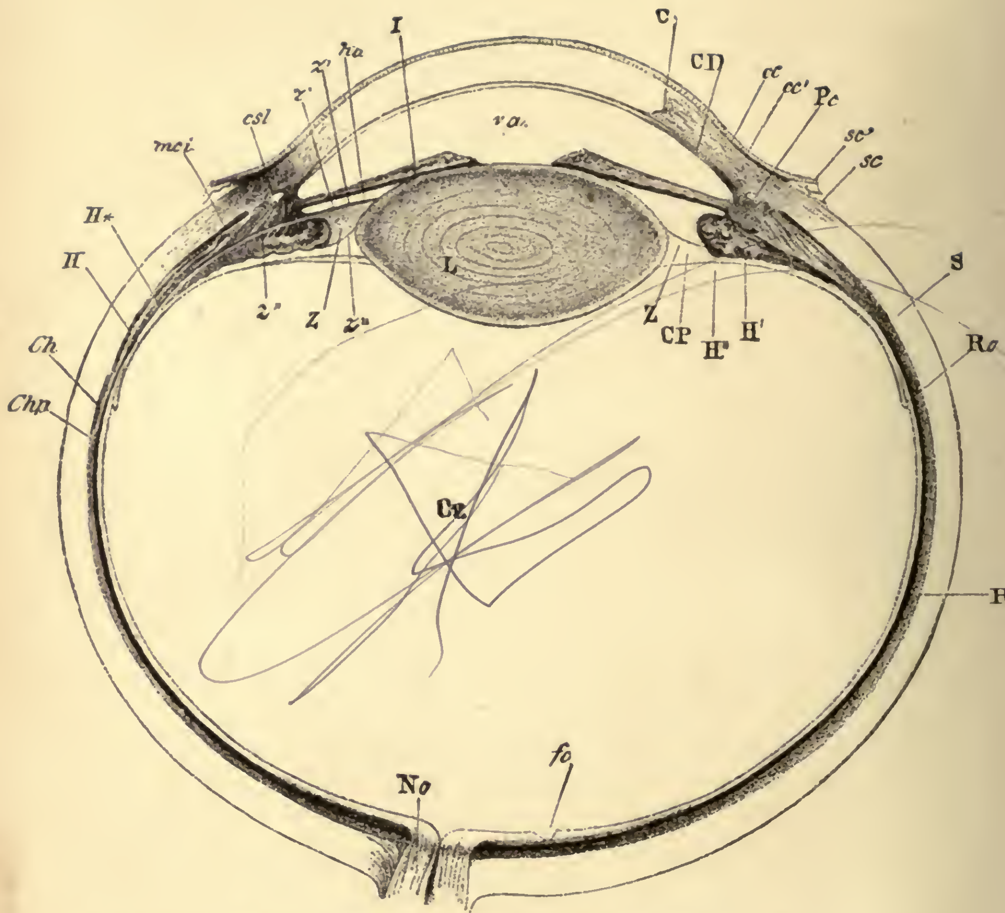


PLATE I.—HORIZONTAL SECTION OF THE HUMAN EYE. (SOELBERG WELLS.)

C—Cornea.
cc—Anterior Elastic Lamina.
cc'—Epithelium of the Anterior Surface of the Cornea.
CD—Membrane of Descemet, or Posterior Elastic Lamina
CDE—Epithelium of the Posterior Surface of the Cornea.
S—Sclerotic.
sc—Tenon's Capsule, the Connective-Tissue Layer.
sc'—Conjunctiva, and its Epithelium.
csl—Canal of Schlemm.
Ch—Choroid.
Cp—Pigment Layer of the Choroid.
Pc—Ciliary Processes.
mci—Ciliary Muscle, Longitudinal Fibres.
I—Iris.
ip—Pigment Layer of the Iris.
i—Iritic Angle.

FIRST LECTURE.

ANATOMY.

Orbits—Their formation—Parts contained in—The eyeballs—The tunics—Imaginary points—The globe of the eye—Anterior and posterior pole—Optic axis—Equator and planes—Arteries of—Optic nerve—Nerves of motion—Sympathetic nerves—The muscular system—Centre of rotation—Primary and secondary position—Ciliary muscle—Cornea—Aqueous humor—Crystalline lens—Vitreous body—Retina—Macula lutea.

Gentlemen :—You will agree with me in the fact, that the necessity of perfect sight, and the correct appreciation of all the objects surrounding us, is not only absolutely essential to our happiness, but also necessary for our success in life.

Under these circumstances the study of the visual apparatus and the efficiency of the organs of vision will not only be very interesting, but also a study that will well repay you in the work of your professional life.

Now, there are certain parts not directly connected with vision that we should consider, such as the anatomy of the orbits and their contents, which will better enable us to appreciate the blessings of sight. We will also learn how perfect in their action, and how delicate in their mechanism, are the eyeballs and their muscular system.

Few of us ever realize, when we pass the eye over the pages of our books, or look from one object to another, or to a distance and then near at hand, the changes that take place in the mechanism of the eyeball. I use the word *mechanism* because we must study the eyeball as an optical instrument, remembering only that it is always

subject to the changes that nature sees fit to impose. Although the eye is not a perfect optical instrument, we must admit that its power of self-adjustment to rays of light from any luminous point is far more perfect and simple than that of any instrument that has been devised by human ingenuity.

I shall endeavor to treat the subject of vision and the errors of refraction, not from a scientific point of view, but shall place facts before you in such a simple yet complete manner that they can be readily understood; I will then leave the subject to your own inclinations and to earnest clinical work. You may learn many things from our various excellent writers, but, to perfect yourselves in the correct detection of the errors of refraction, your eye and hand must become accustomed to do their work, just as the skill of the artisan is shown in the work that he performs.

No man can accustom his eye to the detection of refraction with the ophthalmoscope until he has devoted many hours to the use of the instrument. Some of our best ophthalmologists will differ very essentially on the degree of refraction, when they estimate it with the ophthalmoscope: this I have known to occur in several instances.

I can only teach you the manner of using your instruments and the method by which you will obtain certain results; all the rest I must leave to your own constant work and study.

Let us, therefore, look at the eyeball and its appendages from an anatomical point, and consider its surroundings, or the parts which serve to protect and nourish the eyeball; and then pass on to the parts most intimately concerned in refraction.

The eyeballs rest in the bony orbits situated in the anterior portion of the skull. These orbits protect them

from external violence and serve to form points of attachment for the muscles which move them, and the tissues that occupy the back portion of the orbits form a cushion upon which the eyeballs rest. These orbits are situated on each side of the median line and are shaped like a four-sided prism, with their bases outward. The inner sides of these two cavities run parallel, with the ethmoid bone between, while their axes point toward each other, forming an angle of about 42 degrees.

They are about $1\frac{3}{5}$ inches deep, and are formed by seven cranial bones, three of which are common to both cavities; the roof of each cavity, slightly concave, is formed by the orbital plate of the frontal bone, and at the apex is a small portion of the lesser wing of the sphenoid.

The floor is formed partly by the bones from the inner wall, except in front by a portion of the malar bone, and near the apex by a part of the palatal and superior maxillary bone.

The median or inner wall is formed by the superior maxillary, the *os planum* of the ethmoid, and the lateral surface of the lachrymal bone; while the lateral or outer wall of the orbit is principally composed of the greater wing of the sphenoid and the frontal process of the malar bone.

The openings into these two cavities are four in number. The largest, lying between the lateral wall and the roof, is the anterior lacerated foramen or sphenoidal fissure, which serves for the passage of the third, fourth, sixth, and ophthalmic division of the fifth nerves and also the ophthalmic vein. At the apex we have the optic foramen, a funnel-shaped passage for the optic nerve and the ophthalmic artery, while at the inner junction of the median wall and the roof are the anterior and the posterior ethmoidal foramen for the passage of the ethmoidal vessels and nasal nerve.

These two bony cavities contain within their walls all the various tissues that exist in the other parts of the body, as we have connective tissue, adipose and muscular tissue, cartilages, veins, arteries, nerves, lymphatics, and various tissues peculiar to the eyeball and not found in other parts. The orbits are lined by a layer of periosteum, which forms a thick tendinous ring around the optic foramen for the attachment of the muscles which move the eyeballs in various directions.

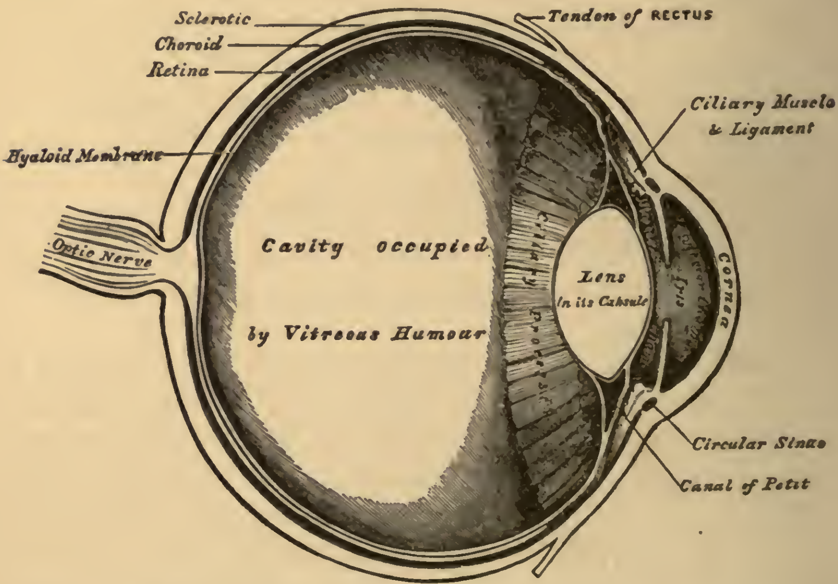


FIG. 1.—A VERTICAL SECTION OF THE EYEBALL. ENLARGED.—AFTER GRAY.

The connective and adipose tissues, with the muscles, form a cushion upon which the eyeballs rest, protecting them from any violence from without. As this connective tissue surrounds the eyeballs and muscles, it serves as a shield and protection, while holding the muscles in their proper position. The anterior portion, covering the front of the eyeball, is called Tenon's capsule; and that portion directly beneath the conjunctiva, the subconjunctival tis-

sue ; while all that part covering the posterior portion of the eyeball, is called *Bonnet's* capsule.

Lying in the anterior portion of the orbits and protected by the eyelids, while they are held in position by the muscular system, are the essential parts, or the organs of vision, the eyeballs. These are in the form of a sphere, with the segment of a smaller sphere projecting from their anterior surfaces.

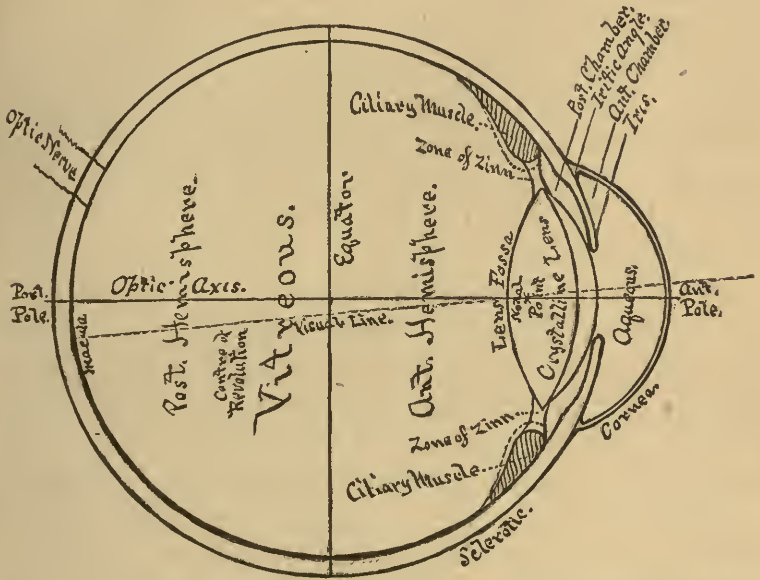


FIG. 2.—DIAGRAMMATIC REPRESENTATION OF A SECTION OF THE HUMAN EYE.

The eyeball is composed of three tunics, the outer one being the sclerotic, with the cornea anteriorly, and beneath this, in front, is the uveal tract, consisting of the iris, the ciliary body, and choroid, or tunica vasculosa. These parts are all intimately connected ; while internal to them is situated the most sensitive nervous layer, the retina. Within this cavity, formed by these tunics, we have three important humors,—the aqueous, the crystalline lens, and the vitreous body.

Taking the eyeball as a sphere, we fix upon its surface certain imaginary points, which I wish you to remember. They will be of service to us in the study of refraction, and we will give them names similar to corresponding points upon the earth.

We have, first, the anterior pole, at the centre of the cornea, while the posterior pole lies at the centre of the fundus, or back part of the eye ; and an imaginary line running from pole to pole would form the optic axis. But you must not confound this with the visual axis or line, which passes from the centre of the macula lutea, or yellow spot, outward through the cornea, within, and a little above, the anterior pole, directly to the object at which we are looking. This line crosses the optic axis at the nodal point, which lies near the posterior surface of the crystalline lens.

If we now draw a line around the eyeball at its centre, it will form the equator of the eye, and the equatorial plane will be one parallel to the equator, dividing the eyeball into anterior and posterior hemispheres. At right angles to this equatorial plane we may have any number of different meridional planes at any degree on the arc of the circle ; their axes also coinciding with the visual axis. If you will remember that the refractive power of the eye may be different in each one of these planes, it will assist you in the study of refraction.

The arterial system of the eyeball and orbits consists only of the ophthalmic artery and its branches, which proceed from the internal carotid. This vessel supplies all the tissues of the orbits and eyeballs, with its terminal branches extending outward upon the face. The principal branches, in which we are most interested, are the ciliary branches, long and short, and the central artery of the retina, the *arteria centralis retinæ.*

In the nervous system of the orbital cavities we find the nerves of motion and sensation, chief of which is the optic nerve, passing from the brain, through the optic foramen, to the eyeball. This is surrounded by a delicate nerve sheath, a continuation of the pia mater. As this nerve passes forward and enters the sclerotic, its fibres

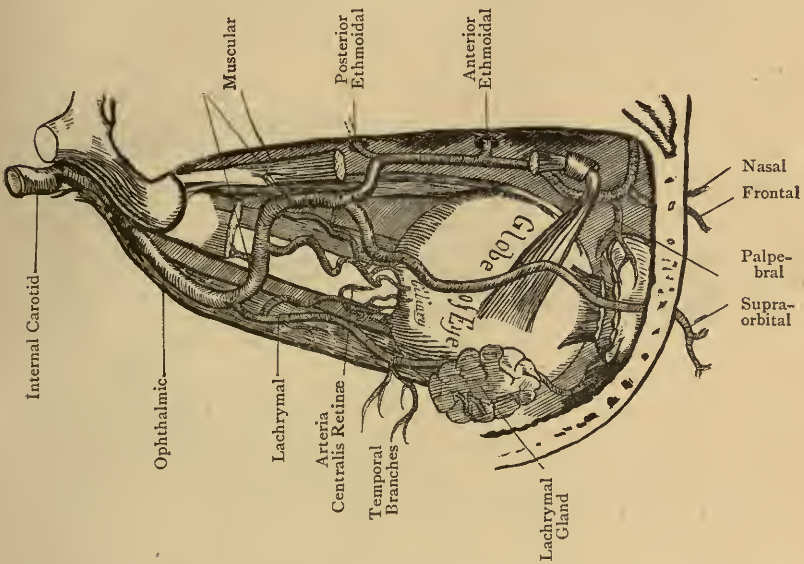


FIG. 3.—THE OPHTHALMIC ARTERY AND ITS BRANCHES, THE ROOF OF THE ORBIT HAVING BEEN REMOVED.

pass through the meshes of the lamina cribrosa, a short distance to the inside of the posterior pole. It then expands in all directions, spreading out over the internal surface of the eye-ball, forming the retina.

The nerves of motion that will interest us in the study of refraction are the third, fourth, and sixth, which have their terminal branches in the various muscles that control the movements of the eyes. The third or motor oculi supplies all the muscles within the orbit, except the superior oblique, which is supplied by the fourth or patheticus, and the external rectus, supplied by the sixth or abducens. This third nerve also sends branches to the

muscle of accommodation, and to the sphincter muscle of the iris, though these fibres are supposed to have a separate origin in the brain.

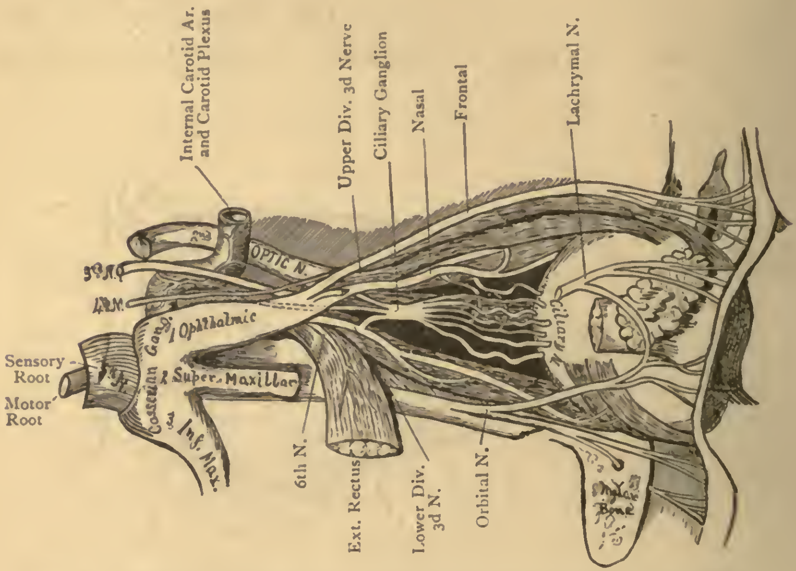


FIG. 4.—NERVES OF THE ORBIT AND OPHTHALMIC GANGLION.—SIDE VIEW.

The sympathetic branches joining the different nerves send filaments to the dilator muscle of the iris, and so act antagonistically to the filament of the third nerve.

The muscular system of the orbits consists of six muscles, which move the eyeballs in any direction about a common centre of rotation, directing both eyes simultaneously toward any object. These are voluntary muscles, being under the control of the will, and take their origin principally from the tendinous ring, formed by periosteum, around the optic foramen.

The four recti muscles may be considered almost as one, as they all have the same origin, around the optic foramen. These pass forward in the sheaths formed by the connective tissue of the periocular space, and are in-

serted by a tendinous expansion into the sclerotic, a short distance behind the limbus of the cornea.

Their actions, singly, move the cornea as follows: Upward, by the superior rectus; downward, by the inferior rectus; outward, by the external rectus; and inward, by the internal rectus. The combined action of the superior and the inferior rectus also turns the eyeball inward.

The remaining muscles are called the superior and inferior oblique, having their point of action from the inner angle of the orbits. The superior oblique arises from the

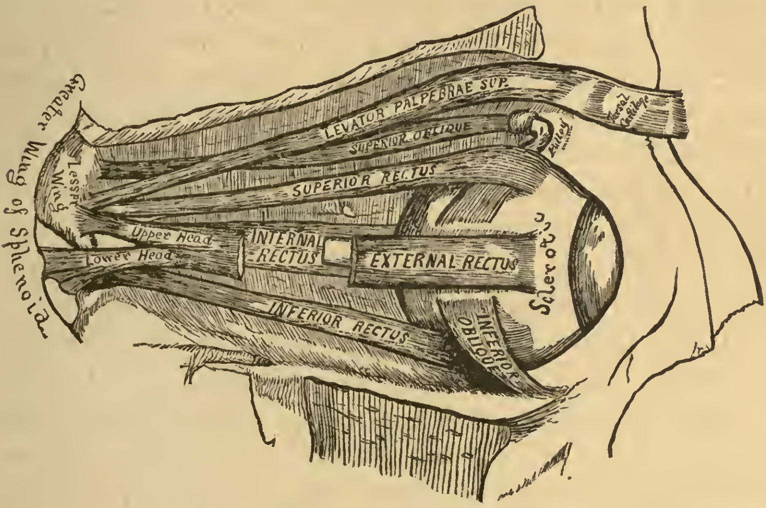


Fig. 5.—Muscles of the Right Orbit.

optic foramen on the inner side, and as it passes forward toward the upper and inner angle it becomes tendinous, passing around the trochlear process of the frontal bone; it again becomes muscular, and then passing backward and outward beneath the superior rectus, it is inserted by a broad and flat tendon into the sclerotic, between the insertion of the superior and the external rectus. The action of this muscle rotates the eyeball on its axis, and turns the optic axis downward and outward.

The inferior oblique muscle, arising from the superior

maxillary bone, at the inner portion of the floor of the orbit, and passing beneath the inferior rectus, outward and backward, is inserted into the sclerotic, between the entrance of the optic nerve and the tendon of the external rectus. Its action serves to turn the cornea upward and outward, and at the same time rotate the eyeball on the optic axis.

This muscular system will turn the eyeball in almost any direction when acting singly; while the action of any two related muscles will turn the eyeball in a direction between the two muscles, as in the action of the superior and the internal rectus the eyeball will move directly upward and inward; and so with the other muscles. It is always a difficult matter to understand and appreciate the different directions in which the eyeball is moved and the action of the various muscles concerned; but if we will remember the common centre of rotation and the origin and insertion of those six muscles, their action, either combined or singly, will be found to be very simple.

When the muscular system is at rest these muscles, by their tonicity, keep the eyeball steady against the cushion of adipose and connective tissue in the orbit. The optic axes are directed forward, each separate muscle acting in antagonism to its opposite; then, as the eyeball is moved in any direction, it turns on the *centre of rotation.* This point is situated on the optic axis, about fourteen millimetres behind the cornea and ten millimetres in front of the posterior surface of the sclerotic. This is the point of intersection of the various axes of rotation of the eyeball.

When the muscular system of the eyeballs moves them both in harmony, it is called the *associated* movement, and the visual lines are parallel; while, when we use the muscle of accommodation, we have the *accommodative* movement.

These recti muscles are antagonistic when the action of one muscle is opposed to that of the muscle of the opposite side; while the action of the internal rectus is associated with the action of the ciliary muscle and the iris, in the act of accommodation.

The axis of rotation of the superior and inferior recti muscles lies in the horizontal plane, with its nasal extremity further forward than the temporal; so that the eyeball is carried slightly inward by the combined action

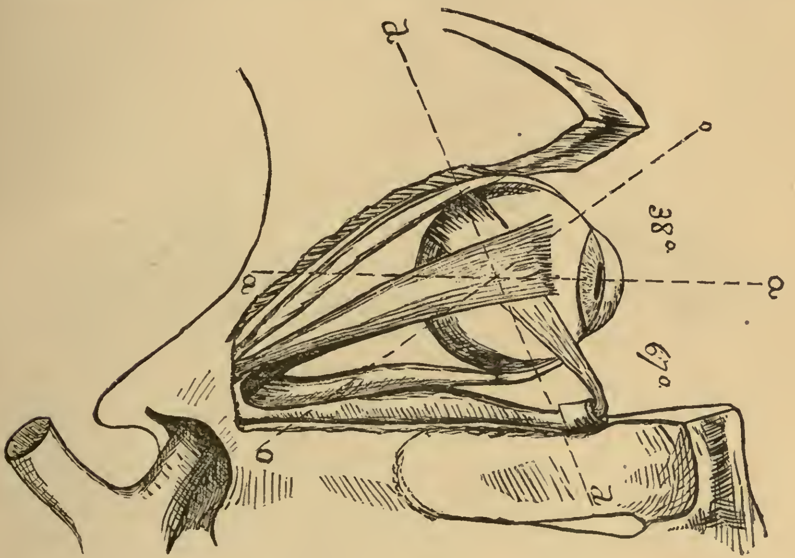


FIG. 6.—THE AXES OF ROTATION OF THE EYEBALLS.—AFTER LANDOLT.

of these two muscles, as their origin is nearer the median line than the centre of rotation. The internal and the external rectus are directly antagonistic, and move the eyeball on a vertical axis of rotation. The axis of rotation of the superior and inferior oblique lying in the horizontal plane forms an angle of 38 degrees with the line of fixation, or the optic axis when at rest.

When we have these muscles in a state of tension, the head erect, the horizontal and vertical meridians in their

proper positions, and the optic axes directed forward, the eyes are in the primary position ; while any deviation from this is called a secondary position. And in all cases, whether primary or secondary, unless there should be some pathological condition, the eyeballs when in use are so directed that direct rays of light fall upon the macula lutea of each eye.

Within the eyeball we have a very important muscle, the *ciliary*, whose action controls our vision for all points nearer than infinity. This muscle arises from the corneo-

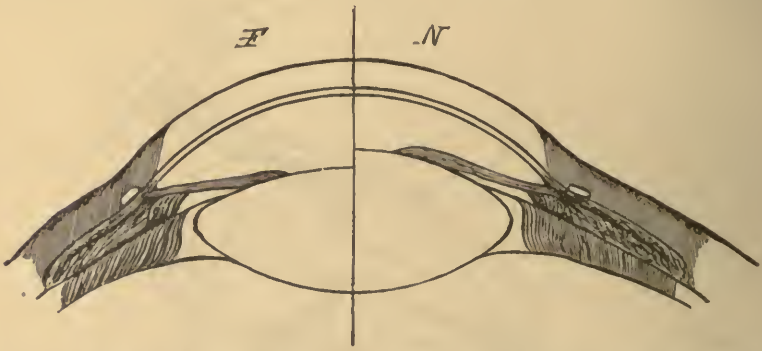


FIG. 7.—SECTION OF THE LENS, ETC.: SHOWING THE MECHANISM OF ACCOMMODATION.

The left side of the figure (F) shows the lens adapted to vision at infinite distances ; the right side of the figure (N) shows the lens adapted to the vision of near objects, the ciliary muscle being contracted and the suspensory ligament of the lens consequently relaxed.

scleral junction, at the inner side of the canal of Schlemm, by a tendinous origin. It is composed of two sets of fibres ; the radiate, which are inserted into the ciliary processes ; and the circular, or circular ciliary, ligament. These fibres are on the inner side, and pass around and within the zone of the ciliary processes. As regards the action of this most important muscle, I think the description in Flint's "Physiology" about the best, which says : "When this muscle contracts, the choroid is drawn forward, with, probably, a slightly spiral motion on the

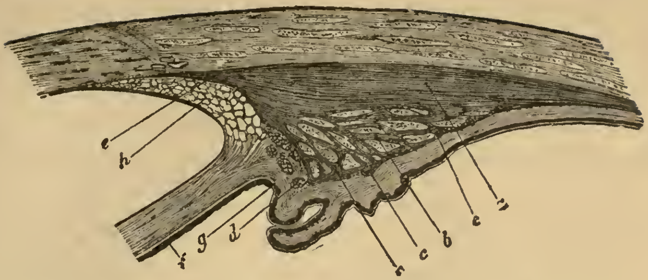


FIG. 8.—SECTION THROUGH THE CILIARY BODY (EMMETROPIA).

Showing the ciliary muscle: *a*, choroid; *b*, radiating fibres of ciliary muscle—the small group of circular fibres are seen lying to the median side of the radiating; *d*, a transverse section of a blood-vessel; *f*, the uvea of the iris; *g*, the pigment layer of the ciliary body; *h*, the spaces of Fontana (rendered too conspicuous).

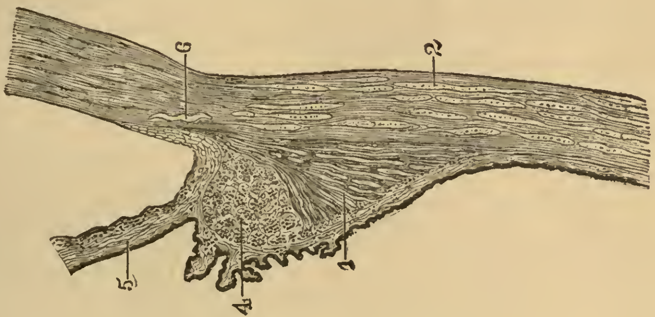


FIG. 9.—SECTION OF CILIARY BODY.

Showing the hypertrophy of the circular fibres of the ciliary muscle in hypermetropia: 1, The radiate fibres of the ciliary muscle; 2, the sclera; 4, the circular fibres of the ciliary muscle; 5, the iris; 6, the canal of Schlemm.

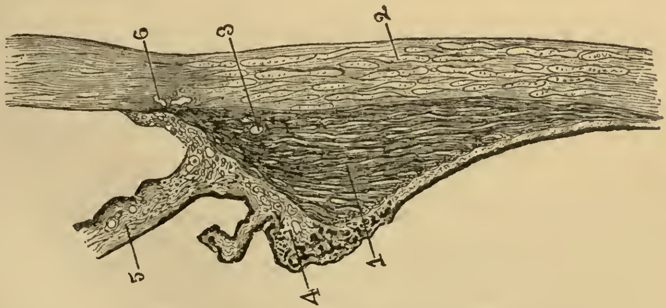


FIG. 10.—SECTION OF CILIARY BODY.

Showing absence of the circular fibres of the ciliary muscle in myopia: 1, The radiate fibres; 2, the sclera; 3, the section of a vessel; 4, the ciliary processes: 5, the iris.

lens. The contents of the globe, situated posteriorly to the lens, are compressed, and the suspensory ligament is relaxed. The lens itself, the compressing and flattening action of the suspensory ligament being diminished, becomes thicker and more convexed, by virtue of its own elasticity."

As by this action of the ciliary muscle the lens is rendered more convex on its anterior surface, increasing its power to bend rays of light, you will understand that the divergent rays from objects within infinity are exactly brought to a focus upon the retina. It is by the action of the ciliary muscle that the mechanism of accommodation is accomplished, and all the requirements of vision are adjusted perfectly.

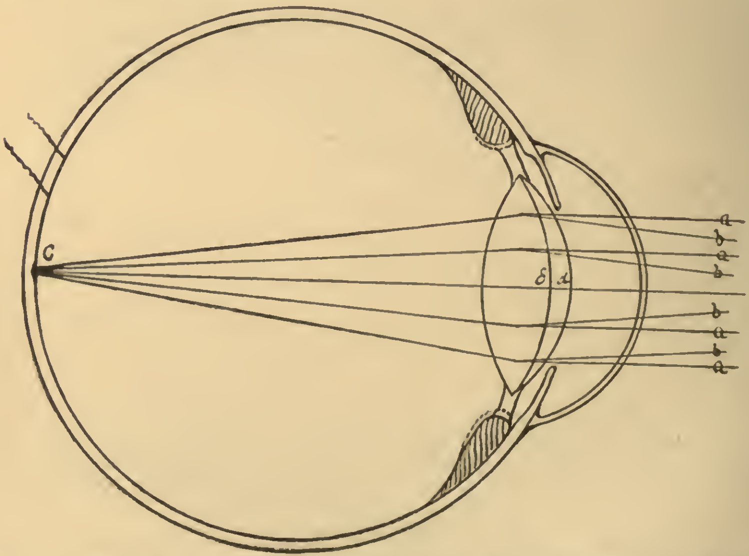


FIG. 11.—DIAGRAM SHOWING RAYS PASSING THROUGH THE DIOPTRIC MEDIA. PARALLEL AND DIVERGENT RAYS HAVING THE SAME DIRECTION AFTER PASSING THE LENS, BY THE ACTION OF THE CILIARY MUSCLE.

In the above diagram the parallel rays are shown entering the eye, *a a a a*, refracted by the dioptric apparatus. With the eye at rest and the anterior surface of the lens

at *e*, they will then focus at the point *c*, on the retina; but when they come from a nearer point, and have a divergent direction as *b b b b*, we find the anterior surface of the lens at *d*, by the action of the ciliary muscle increasing the power of refraction. These rays take the same course from the lens to the retina.

The action of the ciliary muscle is controlled by the ciliary nerves, which pass from their origin in the ciliary ganglion through the posterior portion of the sclerotic.

We will now pass to the anatomical parts of the globe that are directly concerned in the act of vision, as the rays of light are refracted.[1] We consider that when these rays come from an object more than twenty feet distant they are practically parallel, and first impinge upon the corneal tissue, passing through its five layers, as follows: First, the epithelial coat, a continuation of the conjunctival epithelium; second, the anterior elastic lamina; third, the true corneal tissue; fourth, the posterior elastic lamina; and fifth, the posterior epithelium, or *Descemet's* membrane. These five layers form a clear homogeneous membrane that, from its convex anterior surface, has great power in bending or refracting the rays of light, which, as they pass through the cornea, would again become almost parallel, except for the next refractive media, the aqueous humor. This is a clear watery fluid, which fills the spaces of the anterior and posterior chambers between the cornea and lens, and whose power of refraction is almost the same as that of the cornea.

Passing backward we now come to the crystalline lens, lying just posterior to the pupil of the iris, and suspended between the aqueous and vitreous humors by the *zone* of Zinn, or suspensory ligament. This ligament is attached to the anterior capsule of the lens, being a continuation of the anterior portion of the hyaloid membrane; which membrane is also blended with the ciliary

muscle at the ciliary processes, and by this means controls the action of the lens in the act of accommodation. The lens is a bi-convex, transparent body, inclosed within its own capsule, and surrounded at its periphery by the *canal of Petit*, which lies between the layers of the hyaloid membrane.

The lens measures about one third of an inch (eight *mm.*) from side to side, and one fifth of an inch thick. It is less convex in front than behind, except when the ciliary muscle contracts in accommodation, when its anterior surface projects into the anterior chamber, thereby increasing its refractive power and bending the rays to an exact focus upon the retina.

Lastly, in our *dioptric* or refractive media we have the *vitreous body*, which completely fills the rest of the globe of the eye. It consists of a jelly-like, transparent structure, with a central depression in front, the hyaloid fossa for the crystalline lens, and is surrounded by the hyaloid membrane, the anterior portion of which you will remember, divides into two delicate layers on each side of the canal of *Petit*.

The rays of light still further refracted by the vitreous body, now strike upon the retina, and, being brought to complete focus, there produce an exact inverted image of the object from which the rays proceed. The *retina* is a continuation of the optic nerve, expanding outward in all directions, from the nerve entrance to all parts of the inner surface of the globe, until it ends at the ora serrata, near the ciliary processes. It is transparent, grayish in color, about one seventy-fifth of an inch thick, and gradually tapers until, at its periphery, it is about one two-hundredth of an inch. It is composed of nervous elements and connective tissue ; it receives all the visual impressions, and through its nervous power conveys them to the brain.

Before closing this lecture let me call your attention to the *macula lutea*, or the yellow spot of the retina, lying near the posterior pole and between that point and the entrance of the optic nerve. It presents more by its negative characters than by any positive ones. As a rule, you will find no distinct marks of its location in the normal eye, except a slight deepening of the retinal pigment and the absence of blood-vessels : these latter all pass around it. In looking for this spot with the ophthalmoscope you will find it at the temporal side of the nerve entrance, and about two diameters of the nerve distant, on a line with the lower border of the optic nerve. In some cases where we have normal vision the *fovea centralis*, or central depression of the macula lutea, is well marked as a small, irregular spot, due, no doubt, to a large excess of pigment. At this important point in the retina, where all the rays of our direct vision focus, the retina itself is very thin, and only composed of the rods and cones, the essential nervous elements.

It is at this point that the visual axis ends ; it is also the point of perfect vision. As we recede from it the sensibility of the retina becomes less and less, until we reach the ora serrata, at the extreme periphery. The retina extends so far forward that rays of light passing in a straight line which can enter the eye must strike upon it, there producing a more or less distinct image, according to the distance from the macula lutea, or point of perfect vision.

SECOND LECTURE.

REFRACTION.

Dioptric apparatus—Infinity—Refraction of light—Angle of incidence—Angle of refraction—Prisms—Lenses—The bi-convex lens—Principal and secondary axes—The bi-concave lens—The negative focal point—Meniscus and concavo-convex—Dioptric media—Their index of refraction—The iris—Its purpose—Cylindric lenses—The two principal planes—Metric system—The dioptry—Tables of comparison—To change to inches.

GENTLEMEN: As we have studied the anatomical portions of the globe of the eye that are essential to vision, let us now study how these anatomical parts act in bringing the rays of light to a perfect focus on the sensitive retina, and what is the position of the image there formed.

No very considerable time has elapsed since we have mastered the subject of refraction, although glasses were first worn, for presbyopia, in the thirteenth century. Nor did we comprehend how the rays of light were refracted until DONDERS published his classical work, giving to the world a complete exposition of refraction in all the grades of ametropia, and suggested the ready means of correction.

It is HELMHOLTZ to whom we are indebted for the knowledge of the exact refraction of the eye, as, by his instrument, the ophthalmometer, we learn the radii of curvature of the cornea and lens, with the indices of refraction of the various media through which a ray of light passes to the retina.

We consider the refractive parts of the eyeball as the cornea, aqueous humor, crystalline lens, and vitreous

body. These taken collectively, are called the *dioptric media;* which refer to those portions of the eyeball through which rays of light pass that enable us to see, having no reference to the *dioptry.*

All objects send off rays of light in every direction, which are direct or reflected. These rays pass in straight lines, unless they meet some substance, that will either reflect and send them backward, or refract and bend them in their course. This refraction simply changes their direction, when they pass on in straight lines again.

In the study of refraction we consider that all rays of light, either direct or refracted, travel in parallel paths when they come from a distance of twenty feet or more; this distance is called infinity, while all rays that come from a nearer point than infinity are divergent. Theoretically, all rays of light are divergent, as they come from a minute luminous point; but, practically, for any distance beyond twenty feet they are considered parallel.

Thus you will understand that when we look at an object, such as the usual test letters, placed at a distance of twenty feet, the rays of light reflected from the letters will enter the eye parallel, and all those coming from a nearer point than twenty feet, up to the nearest one of distinct vision, enter divergent; and that the nearer to the eye we place the object or letters, the more divergent are the rays of light.

Having just said that all rays pass in straight lines unless refracted or bent, we will now consider how a ray of light is so affected, or, in other words, the subject of refraction of light. The meaning of the word REFRACTION is *bending back*, as you will notice the rays are so bent by passing through certain media, as water or glass.

To illustrate this subject plainly, we take a square box as shown in fig. 12, *M, N, P, O.* If we put a small hole in one side of the box, as at *a*, and allow a ray or beam

of light to pass through this hole, it will strike the bottom of the box at *C*. Now fill the box with water up to the line *sr* and you will see the ray strike at the point *D*; making it very evident that the ray of light, after striking the surface of the water at *B*, instead of passing directly onward to *C*, is bent or refracted backward to *D*.

If in place of water we use some denser medium, such as glass, we will now find that the ray *aB* is still further refracted, and strikes the bottom of the box at *x*. Hence we may conclude that when a ray of light, passing through the air, falls in an oblique direction upon the surface of a liquid or solid body, through which light can

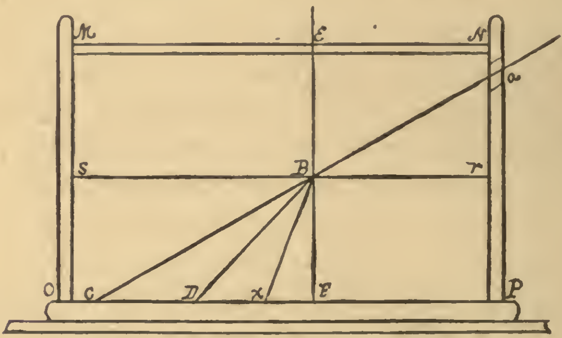


FIG. 12.—REFRACTION OF RAYS OF LIGHT.

pass, it is refracted; and by different bodies in different degrees, according to their density.

Now take a bright piece of money and place it in the same vessel, when empty, at the point *C*, and place the eye at *a*. The coin can be distinctly seen. Fill the vessel again with water to the line *sr*, and the coin is no longer visible at *C*, but must be placed at the point *D*. Hence it follows that the rays of light that proceed from *D* take exactly the same course, or are refracted, when they leave the water, to *a*, as they did when the rays passed from *a* to *D*. So we may again conclude, that when a ray of light passes through a liquid or trans-

parent solid body obliquely to its surface, and enters the air, it is refracted according to the medium through which it passes, *unless* the direction of the rays should be beyond the *limit angle*, when they would simply be reflected by the surface of the water, and would not pass outward so as to be refracted. We have now explained the directions in which rays of light proceed when passing from a rare medium, such as the air, into a dense medium, as water or glass; and also from a dense to a rare medium. Let us consider the rule or method by which we can calculate the direction in which rays are refracted when passing through different media.

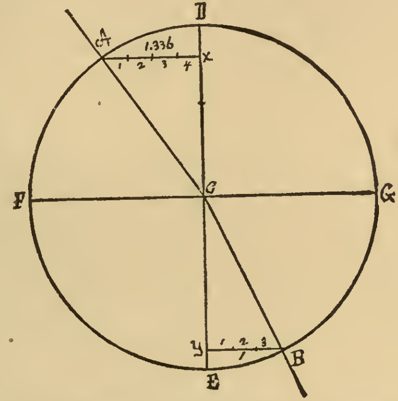


FIG. 13.—ANGLES OF INCIDENCE AND REFRACTION.

For this purpose draw a circle, as *D F E G*, then draw two lines across the circle at right angles, as *D* to *E* and *F* to *G*, making two diameters, one perpendicular to *FG*. Now if a ray of light passes from *A* to *C*, and at the point *C* falls upon a denser medium in an oblique direction, it will be refracted to the point *B*; while another ray, passing from *D* to *C*, and falling perpendicularly to the surface, will pass directly to *E*. Thus we see that a ray passing directly through a dense medium perpendicular to its surface, is not refracted, and that the line *DC* is the normal of the surface at *C*.

Now the angle formed by the lines *A*, *C*, and *D* is called the angle of incidence, and the angle *B*, *C*, and *E* is called the angle of refraction; and if we compare the distance of the line *A* to x with that of the line *B* to y, we will find their lengths are in the proportion of $1\frac{1}{3}$ to 1, or, strictly speaking, if the denser medium be water, 1.336 to 1; and still further that the line *A* to x is called the sine of the angle of incidence, and the line *B* to y the sine of the angle of refraction. You will also notice that the line *CB* is bent toward the perpendicular line *DE*, and that, as shown in the diagram, the proportion of the sine of the angle of incidence is to the sine of the angle of refraction as 4 to 3 when the refracting body is water.

If we now reverse the direction of the ray, allowing it to pass through the dense medium from *B* to *C*, we will find that, as it enters the rarer medium, or the air, it is refracted in the direction *C* to *A*, or away from the perpendicular line *DE*. Thus we have this cardinal rule: that when a ray of light passes obliquely from a lighter or rare medium to a dense medium, it is bent toward the perpendicular; that, when passing from a dense medium to a lighter one, it is bent *from* the perpendicular, and that, when it passes perpendicularly to the surface, coincident with the normal, it is not refracted.

When water is the refracting medium, the sine of the angle of incidence is to the sine of the angle of refraction as $1\frac{1}{3}$ is to 1, or 1.336 to 1, (this number is called its index of refraction, or refractive power), while that of other media, as glass, which is generally used for optical purposes, is about 1.5, though it may vary between 1.526 to 1.534; and the sines of the angles when passing through glass will be about as 1.5 to 1. We find that the refractive index of the dioptric media will vary, as it will be different in the cornea, aqueous, lens, and vitreous body, according to their physiological density.

The substance which is used for the refraction of rays of light, as applied to our study, is flint glass. This solid medium is shaped in various forms, their surfaces being sections of a sphere, with that of a prism as a base. Now, if a section be made through the centre of the different varieties of glasses used in correction of refraction, they will appear as illustrated in fig. 14.

A. The section of a prism, having two plain surfaces inclining toward each other, and a base.

B. A double convex lens, bounded by two convex spherical surfaces, whose centres of curvature are on op-

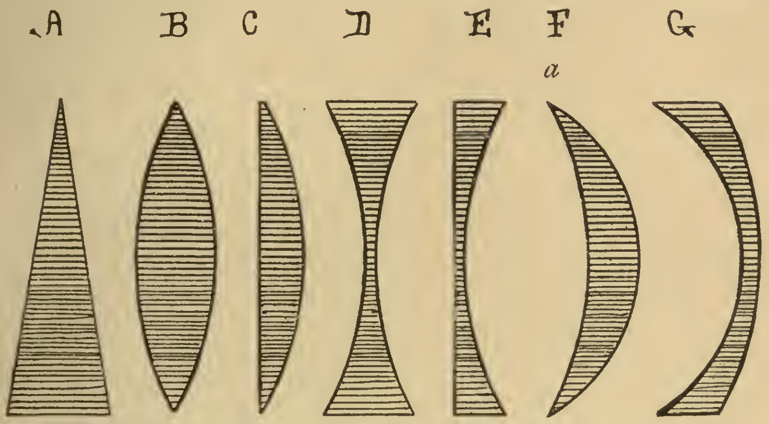


FIG. 14.—SECTION OF A PRISM AND DIFFERENT LENSES.

posite sides to their curved surfaces, and which is equally convex on both sides.

C. A plano-convex lens, bounded by a plane surface on one side and a convex on the opposite.

D. A double concave lens, bounded by two concave surfaces, whose centres of curvature are on the same sides of the lens.

E. A plano-concave lens, bounded by a plane surface on one side and a concave on the opposite.

F. A meniscus lens, bounded by a concave and a convex surface, the convex having the shortest radius of cur-

vature, which two surfaces will meet if continued, as shown at *a*.

G. A concavo-convex lens, bounded by a concave and a convex surface, the concave having the shortest radius: these two surfaces will not meet if continued.

The principal axes of these various lenses will be a line drawn through their centres, at right angles to their plane surfaces; and all rays passing perpendicularly to the plane of the point of contact will not be refracted, but pass directly through.

A ray of light passing parallel to the axis of any of these lenses, and striking at some other point, must fall obliquely upon the surface, and the lens at the point of contact will present the surface of one of the sides of a prism. The ray will then be refracted, the same as when passing through a prism of the same angle.

We will now study how the rays are refracted when passing through a prism of flint glass whose index of refraction is 1.5. Here we must remember our rule: that the sine of the angle of incidence will be to the sine of the angle of refraction as 1.5 is to 1; and that, when passing from the glass medium to that of air, the proportion will be exactly reversed.

A ray of light refracted when passing through a prism is the basis of action in all lenses, which are practically composed of prisms. The course of a ray of light as it passes through an ordinary triangular prism, with the base downward, I will show you in this diagram. (See fig. 15.)

As the ordinary flint glass has an index of refraction of about 1.525, we will use that sum in our calculations, according to our rule for the refraction of rays; remembering that, to be refracted, a ray of light must strike the surface obliquely. We will suppose that a ray passing from *A*, and striking the side of the prism at *C*, is refracted to *E*. Thus, if we draw a circle at *C*, and erect a

line perpendicular to the surface, passing through C, from P to Q, we will find that the sine AD, of the angle of incidence, is to the sine EF, of the angle of refraction, as 1.525 is to 1.

Then, as the ray passes from the prism, we find that it takes the direction of E', being bent from the perpendicular. We draw the circle at C', and erect a perpendicular, P' to Q', and now we find that the sine $A'D'$, of the angle of incidence, is to the sine $E'F'$, of the angle of refrac-

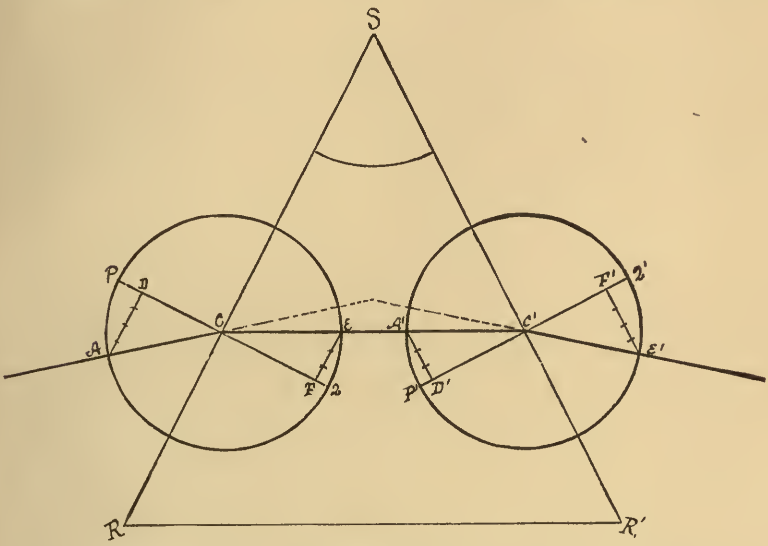


FIG 15.—REFRACTION OF A PRISM, WITH THE ANGLES OF INCIDENCE AND REFRACTION.

tion, as 1 is to 1.525, which proves our simple rule that, when a ray of light passes from a lighter to a denser medium, it is bent toward the perpendicular, and that when passing from a dense to a lighter medium, it is bent from the perpendicular, according to the index of refraction of the substance through which it passes.

You will therefore notice that a ray of light must strike the surface obliquely, when it will be refracted according to the index of refraction; that the ray that passes in a

line with the perpendicular will *not* be refracted, as it cannot be bent toward, or from, a line with which it is coincident, and that consequently it will undergo no deviation.

As these rays are consequently bent toward the base of the prism, you will understand the laws of refraction when rays pass through curved surfaces, such as the different lenses, which practically consist of two prisms placed in different positions.

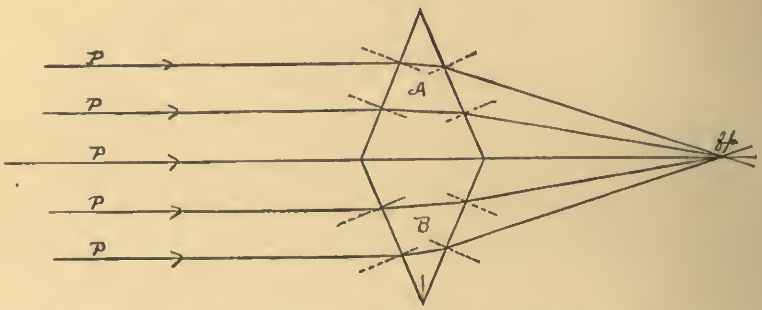


FIG. 16.—CONVERGENCE OF TWO PRISMS PLACED BASE TO BASE.

The first lens in our series, the bi-convex, we can represent by two prisms placed base to base. Now, according to fig. 16, you will see that the parallel rays of light *P*, *P*, *P*, *P*, *P*, as they strike the surface of the prisms *A*, *B*, are bent toward their bases, and as they pass from the prism are still farther bent in the same direction. The central line represents the axis, while the dotted short lines represent the perpendiculars at the points of contact for the rays. As these rays are refracted after passing through the prism, they must meet at a point on the axial line, which we find at *fp*. This will be the positive focal point, or the focal distance of the lens. Also, if rays of light should diverge from a luminous point at *fp*, they would pass through the prism in the same lines and emerge parallel.

You will note that the angle of refraction of any prism

is always the same, no matter in which direction the rays of light may pass. This same explanation holds good in the case of a bi-convex lens, whose curved surfaces are simple minute planes of a number of prisms with their bases together.

Now if the surfaces of a lens are perfectly round, being sections of a perfect sphere, it is called a spherical bi-convex lens; and the ray of light that passes directly through the centre, in line with the perpendicular, is not refracted, and is called the axial ray of the lens.

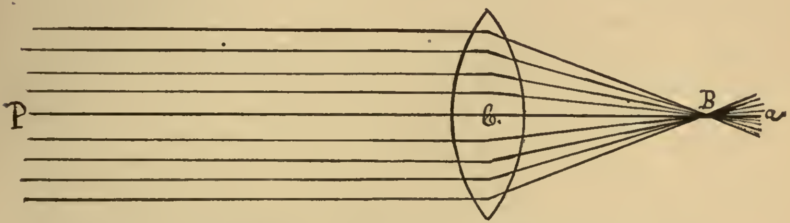


FIG. 17.—A BI-CONVEX LENS AND ITS POSITIVE FOCAL POINT.

In a bi-convex lens the parallel rays from infinity, coming from a direction *P*, will fall upon the convex surface of the lens *C*, and, passing through, will be bent by the lens until all the rays will meet at the positive focal point *B*, and then passing onward will diverge; while the axial ray, *P* to *a*, passing in the centre, and striking the surface of the lens parallel to its perpendicular at that point, will pass onward without any deviation.

We may also have certain rays of light striking the lens on other portions of its surface, and which pass through without refraction, as all those rays that enter the lens parallel to the perpendicular at the point of entry are not refracted. These rays are called the secondary axes, and all rays passing parallel to them will be brought to a focal point on each secondary axis.

In the bi-convex lens *C*, fig. 18, with parallel rays of light passing in three directions, as at *A*, *B*, and *B'*, the princi-

pal axis and focus are found on the line *A* to *A*, while the secondary axes and foci are shown at *B* to *B*, and *B'* to *B'*. The secondary axes *D* and *D'* strike the surface coincident with the normal at that point, and consequently pass directly through the lens, while all other rays parallel to these axes must strike the lens obliquely, and will focus at their respective secondary focal points on the secondary axes, as shown by the points *sf* on the axes *B* and *B'*, while we find the principal focal point *pf* on the principal axis *A* to *A*.

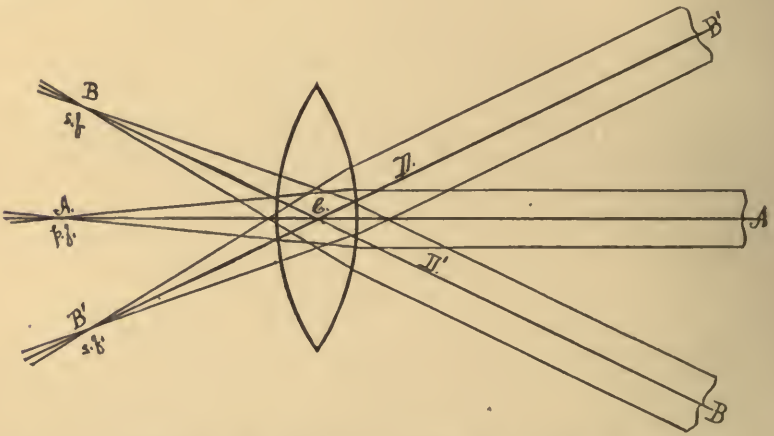


FIG. 18.—PRINCIPAL AND SECONDARY AXES, WITH THEIR FOCAL POINTS.

All these secondary axes must pass through the centre of the lens at the nodal point, as you will see in fig. 18, and we find that all rays of light that coincide with the principal or secondary axes are not refracted, but that all other rays parallel to these axes, when passing through a bi-convex spherical lens, are brought to a focus at the centre of curvature of its curved surfaces. These focal points always rest on the principal or secondary axes, the first being the principal focal point, and its distance from the optical centre of the lens represents the principal focal distance, or the refractive power. When we have reference to a lens of any kind, and speak of the focal distance,

you will understand that a 12-inch lens, for instance, has its focal point at twelve inches from the optical centre. Now each lens, either positive or negative, has practically two nodal points, situated on the axis, and called the anterior and posterior. These two points coincide with the two principal points, situated on the principal axis, at the optical centre of the convex surfaces. Hence all the rays of light that strike the surfaces of the lens directed toward a nodal point will pass through the optical centre of the lens, and emerge as if they came from the other nodal point, in a direction parallel to that of the incident ray.

LANDOLT tells us that in a lens surrounded by a single medium, as the air, the radius of the first surface is to that of the second, as the second focal distance of the first is to the first focal distance of the second; that, in order to find the optical centre of a bi-convex lens, the thickness of the lens must be divided into two parts, which will be to each other as the radii of the corresponding surfaces. Such being the case, the optical centre will be in the centre of the lens when the curved surfaces are equal, and nearer the more convex surface when they are different; and further, "every incident ray refracted by the first surface in such a way as to pass through the optical centre, emerges from the system in a direction parallel to its primitive one."

Let us illustrate this by the following diagram, fig. 19. On the principal axis we have the two curved surfaces, one more convex than the other, representing a section of a bi-convex lens. Let us draw through the centre of curvature, C' and C'', of the two surfaces of the lens two parallel rays, $C'J'$ and $C''J''$. The planes tangent to the refractive surfaces at J' and J'' are parallel, since they are perpendicular to the parallel rays $C'J'$ and $C''J''$. Hence if the ray TJ' meet the first surface at such an angle that it follows $J'J''$ in entering, the cor-

responding emergent ray, $J''U$, will be parallel to the incident ray, for the ray will thus have passed through a refractive medium limited by parallel surfaces, and the point O, where the ray $J'J''$ crosses the principal axis, will be the optical centre of the lens. Then, if these two rays, the incident and emergent, be prolonged backward in a straight line to the principal axis of the lens, we will have the two nodal points. When these lines cross the axis, as

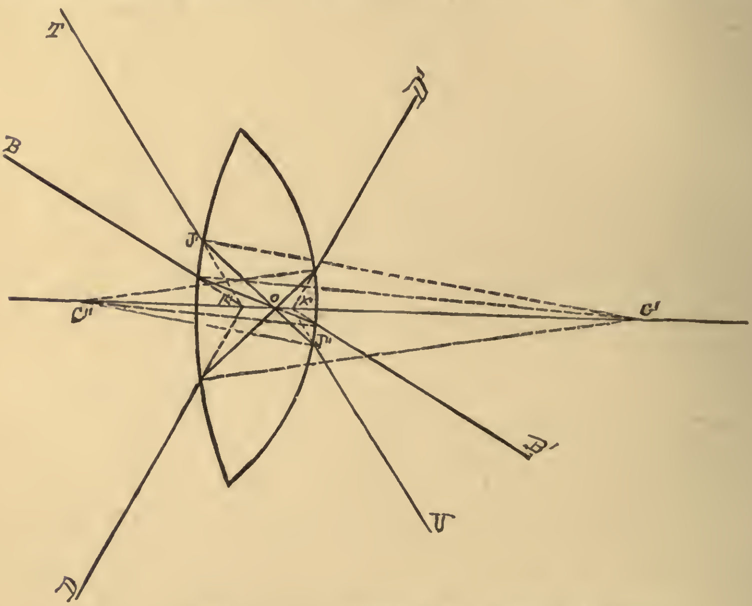


FIG. 19.—THE OPTICAL CENTRE, ETC.—AFTER LANDOLT.

shown by the points K' and K'', so that the incident ray is directed toward the first nodal point, while the emergent ray takes a direction as though coming from the second nodal point, we find the same parallel direction of the rays when coming from the points B to B' and D to D', but each ray passes through the optical centre, O, of the lens, and its direction is either toward or from the two nodal points.

But we must remember that the two nodal points and the optical centre of the lens, as illustrated above, refer to

the path of the rays through thick lenses, while in thin lenses, when the curved surfaces are so near each other, we may simply conclude that our secondary axes pass directly through the optical centre of the lens (see fig. 18), and that all rays that are refracted by the curved surfaces will have the same direction, as they pass through the lens, when coming from different points of the principal axis.

If you will now notice the lens *D*, in fig. 14, you will find that it also represents two prisms, but with their *apices* together and bases outward. Now if we apply the same rules of refraction, as with the convex lens, to these curved surfaces, we will find that as the parallel rays of light emerge from the lens they are divergent, being bent toward the bases of the prisms. If the lens surface be spherical, we have a bi-concave spherical lens. This lens will so bend rays of light that they will diverge in all directions, as if they came from some point behind the lens. It is consequently called a *negative* lens. We find the focal point of this lens situated on the principal axis, at that point where the divergent rays, if they were continued directly backward, would meet. The distance of this point from the optical centre of the lens is called the negative focal distance, which may be represented by inches or dioptries. If we represent this distance in inches, then a bi-concave spherical lens of twelve inches focal distance will cause parallel rays of light to diverge, after they have passed the lens and have been refracted, as if they came from a point twelve inches behind the lens, on the principal axis.

In this diagram, fig. 20, we represent a bi-concave lens at *C*, with the parallel rays from *P*, which, passing through the lens and being bent toward the bases, are divergent, as at *A*, with a direction as if they came from the negative focal point *B*, as shown by the dotted lines. Thus when

the parallel rays strike these curved surfaces they are bent in the same manner as when they strike the surface of a bi-convex lens, but the curvature is different, as the bases are now outward; therefore the direction of the rays is divergent as they pass through the lens.

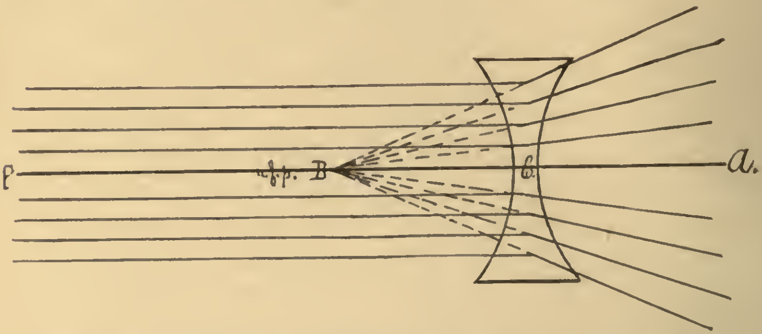


FIG. 20.—A BI-CONCAVE LENS, WITH ITS NEGATIVE FOCAL POINT.

The remaining lenses in fig. 14 all refract light on the same principle and in the same manner, according to the curved surfaces that are presented to the rays of light; those that are convex bringing the rays to a positive focus, and those that are concave causing the rays of light to diverge as if they came from the negative focal point, *i. e.*, behind the lens. But I wish to call your attention to the lenses marked *F* and *G*. These are called *meniscus* lenses. The first one, *F*, has a negative and a positive curved surface, but the curvature of the positive surface being so much greater than that of the negative surface, the rays of light, after they pass through the lens, are brought to a positive focal point; while in the lens *G*, called a *concavo-convex*, the negative surface has the greatest refractive power, and now the rays, as they pass through the lens, diverge from the negative focal point.

Let me illustrate this to you by a reference to the meniscus lens *F*, in which we will suppose that the curvature of the negative or concave side of the lens is equal to a bi-

concave lens of $\frac{1}{20}$, and that the curvature of the positive or convex side of the lens is equal to a bi-convex lens of $\frac{1}{10}$: *thus* the positive focal power of this meniscus lens will be equal to $(+\frac{1}{10}) - (-\frac{1}{20}) = +\frac{1}{20}$. The power of the convex surface is neutralized by the concave surface, according to their respective curvatures, or their refractive power. You will find that most of the lenses in the spectacles and eye-glasses of the shops, particularly those of low power, are ground according to the above method.

The particular advantage about these meniscus lenses is, that they give us much more correct secondary axes, and when adjusted to the eye yield more perfect vision through the periphery of the glass, rendering the field of vision much larger and more distinct.

I wish you to remember that the angle of refraction is always the same when passing through a concave or a convex lens. You will note that, when the luminous point is at the focal distance of a convex lens, the emergent rays are parallel, but if we move the luminous point farther back from the lens, we now find that the emergent rays are convergent; while, if we move the luminous point nearer to the lens than the focal distance, the emergent rays become divergent, as you will see by this diagram:

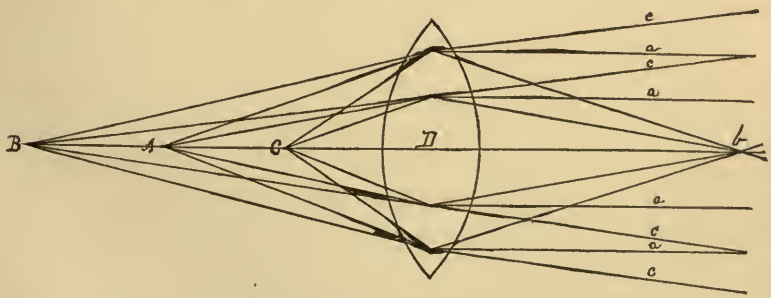


FIG. 21.—DIAGRAM SHOWING THE ANGLE OF REFRACTION IN A BI-CONVEX LENS.

In the above figure we represent a bi-convex lens at D and the focal point at A. Now, rays from that point will

pass beyond the lens in parallel lines, *a*, *a*, *a*, *a*, but if we move the luminous point back to *B*, we find that the emergent rays are convergent, with the same angle of refraction, and if continued would meet at *b*. Then if we carry the luminous point nearer the lens, inside the focal point to *C*, the emergent rays pass beyond the lens in a divergent direction toward *c*, *c*, *c*, *c*, with the angle of refraction the same as when the rays proceeded from the principal focal point. We have the same result with the concave lens, but when the luminous point is nearer the lens than its focal point, the emergent rays are more divergent than the refractive power of the lens, and they cannot be made convergent.

This fact of the angle of refraction being always the same is beautifully illustrated in the human eye, as I shall show you when we study the refraction of the dioptric media, which, taken collectively, would be represented by a bi-convex lens of the same focal power.

When a ray of light parallel to the visual axis strikes the cornea and passes through, it is first refracted by the outer surface according to the rules of refraction. The index of refraction of the cornea is about 1.390, and the radius of curvature 0.28 to 0.32 inches. The rays then pass onward as shown in the diagram, fig. 11, page 14. Through the aqueous humor—whose index of refraction is equal to 1.336, they now pass through the crystalline lens and its capsule, with a mean refraction of 1.3839, and finally through the vitreous humor, with an index of refraction of 1.339, and all the entering rays, by the refraction of these various media, are brought to a focus upon the retina, on the fovea centralis at the yellow spot.

You will see by this that the indices of refraction of these different media forming the dioptric system, through which the rays of light pass, are nearly all the same ; consequently the principal bending or refraction of the rays

of light will take place at the outer surface of the cornea, as at that convex spherical surface the rays pass from a light medium, the air, to a denser medium, the dioptric media, and focus upon the retina at the macula lutea, in the emmetropic or normal eye, the ciliary muscle being in a state of complete relaxation.

As these rays pass through the dioptric media, I wish to call your attention to the iris, which lies between the anterior and posterior chambers of the eye, with the cornea in front, and the anterior capsule of the lens behind. This is an annular opaque diaphragm shown by the colored part of the eye, with an aperture in the centre called the pupil. This opening is a little downward and to the inner side of the optic axis, this pupillary space in man being always circular. We find that the iris has two sets of muscular fibres, connective tissue, and pigment. The muscular fibres are, first, the circular, which receive their nervous supply from the third nerve, or motor oculi communis, by a filament which comes through the ophthalmic ganglion, and the radiate fibres, which are controlled by the sympathetic system of nerves, these radiate fibres being antagonistic to the circular ones.

The object of the iris is very similar to that of an ordinary diaphragm in an optical instrument. As the nervous system is stimulated by the illumination and light that passes in the eye as well as in the act of accommodation, so the iris regulates the amount of light passing to the retina. In a bright light the iris is contracted and the pupil very small, while at night, in a subdued light, the iris is dilated and the pupil large. The iris also serves to correct the spherical aberration of the cornea or lens, as by its contraction it will cut off all the peripheral rays that pass through the margins.

For the purpose of correcting errors of refraction in the eye, and found in all the cases of trial glasses, we have sets

of lenses whose action is quite different from that of those hitherto described. These are called cylindrical lenses, as they are practically segments of a cylinder with the *axis* of the cylinder at *right angles* to the refracting surface; they are generally plane on one side, with the refracting surface on the other, and may be either concave or convex. You will remember the lenses I have spoken about are all perfectly spherical, with their refractive power exactly the same in all meridians, so that the rays are either brought to a positive focus, or diverged as from a negative focus.

Now if we study the action of the cylindrical lens, we must consider chiefly all the rays as passing in two principal planes at right angles to each other. While the light also passes in any number of intermediate planes, yet the rays are so bent that in the convex cylindrix lens they will focus at a positive point, there simply forming a line, and not a single point, as in a spherical lens.

The two principal planes of the eye are generally vertical and horizontal, with the intermediate planes (let me here refer you to the Lectures on Astigmatism); but you must remember that these principal planes will always be at right angles to each other, and may be at any degree of the arc of a circle, as I have illustrated by this diagram:

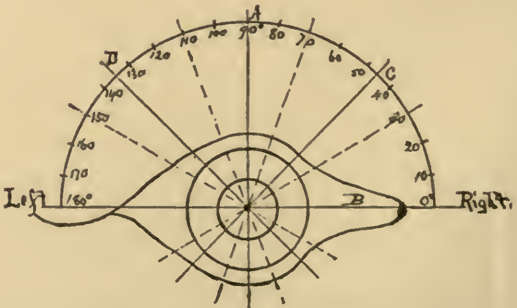


FIG. 22.—THE POSITIONS OF THE MERIDIANS OR PLANES.

The vertical and horizontal planes are shown by the lines *A*, *B*, but instead of that position one principal plane may be at *C*, or 45°, and the other will then be at *D*, or 135°, or these two principal planes may be at any of the meridians on the arc of a circle. Then if we make a glass whose refractive power will be only on the rays of light of one meridian, the rays that pass in the meridian at right angles to that will pass parallel, and are not refracted.

Now, a cylindrical lens is one that is a section of a cylinder; for if we take a cylinder of glass, with the axis running directly through its centre, and cut off a section parallel to its axis, the rays of light that pass through in a plane that is the same as the axis will not be refracted; but all those passing at right angles to that plane will be either convergent or divergent, according to the refracting power of the glass and the radius of curvature.

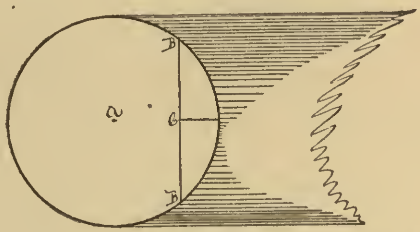


FIG. 23.—END OF CYLINDER, FROM WHICH THE CYLINDRIC GLASS IS CUT.

In this diagram we have the end of the cylinder of glass, with its axis at *a*. If we make a section at *B*, the part cut off will form a plano-convex-cylindric lens; a section made through this at *C* will present the surface of a rectangle, and all the rays in that plane will strike the glass parallel to its perpendicular and will not be refracted.

The action of a plano-convex-cylindric lens is shown in the diagram on p. 38, in which *A* shows the action of parallel rays of light in a plane at right angles to the axis of the glass; and *B*, the parallel rays in a plane coincident to the axis. Hence we have this rule: that the cylindric

lens will only converge or diverge all rays of light that pass at right angles to its axis, according to the refractive power; consequently the refracted rays of a cylindric glass are never brought to a focal point, but will form a straight line on a screen placed at its focal distance.

In the complete cases of trial glasses as found in the shops, we have thirty-two pairs of each, convex and concave spherical glasses, either with ground edges or set in frames with handles; also nineteen pairs of each, convex and concave cylindric glasses, with the axis of each glass marked by a small line at the edge.

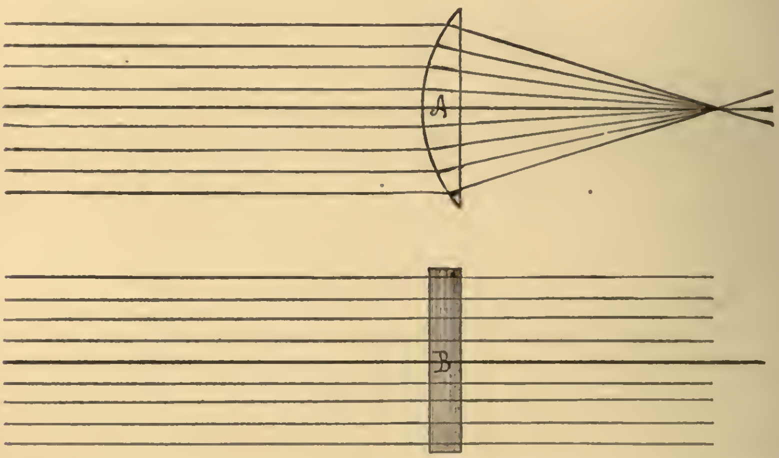


FIG. 24.—PLANES OF LIGHT WITH REFRACTION, IN THE TWO PRINCIPAL MERIDIANS OF A CYLINDRIC LENS. *B*, THE AXIAL PLANE.

There is also a metal disc, for covering the eye; a stenopaic slit, for testing the meridian, the opening being adjustable; a set of prisms with a principal angle of from 2° to 20°; sets of colored glasses, different shades of red and blue; and a trial frame, in which any of the glasses may be placed—the whole in a neat rosewood or leather case. With these trial cases you can test all varieties of refraction.

This completes the description of the action of the vari-

ous lenses found in the cases of trial glasses. Let us now study the method of using these glasses for the correction of the errors of refraction as found in the human eye. I shall give you illustrative cases that may require any of the spherical lenses, separate or combined, for the correction of refraction and the relief of asthenopia.

I have used the word inches in designating the focal distance of the lenses. But, at the present time, there is a strong tendency among all ophthalmologists to use the French metric system to designate the focal strength of a lens. You should therefore familiarize yourselves with that system, as compared with the old method of notation.

The old method was somewhat unsatisfactory, on account of the difficulty of adding or subtracting the various fractions in compound lenses, and also in the varying size of the inch of different countries, as follows :

The Paris inch,	=	27.07	millimetres.
The English inch,	=	25.3	"
The Austrian inch,	=	26.34	"
The Prussian inch,	=	26.15	"

You will note that there is a wide disproportion in this measure, a lens of 5 inches [English] being quite different from one of 5 inches [Paris] in its focal distance ; also, that the standard, one inch, of the old system is so strong that we seldom, if ever, use it. Now, according to the old system, where the standard 1 = one inch, a lens of two inches focal distance will be only one half as strong, = $\frac{1}{2}$, all the weaker lenses in proportion being represented by smaller fractions, as a ten-inch lens = $\frac{1}{10}$, a twenty-inch lens = $\frac{1}{20}$, and so on. Thus a glance will show how tedious, not to say difficult, it is to add to, or subtract from, those fractions.

The new or metric system, which was adopted by the Ophthalmological Society, which convened at Heidelberg in 1875, takes as its unit of measure, a dioptry [D] as pro-

posed by Monoyer, and has one metre as its standard focal distance, represented by $\frac{1 m.}{1}$, then No. 2 = $\frac{1 m.}{2}$, or 2 D, and No. 4 $\frac{1 m.}{4}$, or 4 D. This glass of 4 D is four times as strong as the standard of 1 D, the unit of measure, its focal distance being equal to one fourth of a metre.

This system gives us a series of lenses, of one dioptry between each glass, but as it has been found that for practical use other lenses are needed, we use the fractions of a dioptry to make the regular series, weaker or stronger. Thus, for instance, should we need a lens between 1 D and 2 D, we can add a .5 D to a 1 D, and we have a lens of 1.50 D, equal to about 24 inches; or, should we need a lens weaker than that of 1 D, we may divide it, and have a lens of $\frac{3}{4}$ or 0.75 D, $\frac{1}{2}$ or 0.50 D, and $\frac{1}{4}$ or 0.25 D.

To give you a more correct understanding of the relative value of the old and the new system, the following table will show the focal distance of the lenses in general use. If we take the metre as our standard and consider it equal to about 40 inches (though the metre is exactly equal to 39.5 Paris inches, but for practical purposes we may calculate it as 40 inches), then we can readily find the focal distance of a lens, in inches, by dividing 40 by the number of the dioptry; or we can find the number of the dioptry by dividing 40 by the number of inches.

According to the above method of calculation, the focal distance of a lens is the inverse of its refractive power. Thus a lens of 5 D will equal 40 divided by 5, equal to 8 inches, etc.; or as a lens is the inverse of its refractive power, then the lens of 5 D, $\frac{1 m.}{5}$ or $\frac{100 cm.}{5}$, will give a focal distance of 20 cm., or about 8 inches. In the same way we can find the number of the dioptry, which is the inverse of the focal distance. As, for example, if a lens of 10 inches focal distance be equal to 25 cm., then we have $\frac{1 m.}{25}$, $\frac{100 cm.}{25}$ = 4 D.

COMPARATIVE LIST OF THE METRIC AND INCH SYSTEM.

Dioptries, or new system.	Approximate value in inches.	Actual value in inches.
0.25	160	157.4740
0.50	80	78.7370
0.75	53	52.4931
1.	40	39.3685
1.25	32	31.4948
1.50	26	26 2456
1.75	22	22.4963
2.	20	19.6842
2.25	18	17.4971
2.50	16	15.7474
2.75	14	14.3106
3.	13	13.1228
3.25	12	12.1130
3.50	11	11.2481
4.	10	9.8421
4.50	9	8.7485
5.	8	7.8737
5.50	7	7.1579
6.	6½	6.5614
6.50	6	6.0567
7.	5½	5.6240
8.	5	4.9210
9.	4½	4.3743
10.	4	3.9368
11.	3½	3.5789
12.	3¼	3.2807
13.	3	3.0283
14.	2¾	2.8120
16.	2½	2.4605
18.	2¼	2.1871
20.	2	1.9684

You will see by the above tables, or by the simple rules of changing the calculations, taking 40 (39.5) inches as the length of the metre, that you can readily tell the focal distance of a lens, marked in dioptries or inches : as in one case you simply divide 40 by the number of dioptries, which gives you the number of inches ; or you divide 40 by the refracting power in inches,—this giving you the number of the dioptry.

These simple rules of calculation are in constant use, not only in estimating the power of a lens, marked in dioptries or inches, but many of our best ophthalmoscopes are now only marked in dioptries ; and as you may frequently wish to know the focal power in inches, you can quickly do so by these calculations.

As I have not confined myself to any system of notation in this work, and I shall use the inch or the dioptric system as seems most suitable at the time, so I wish you to be familiar with both systems.

In completing your studies on refraction, I would refer you to LANDOLT on "The Refraction and Accommodation of the Eye" for a full and complete explanation of the refraction of light when passing through different curved surfaces. These lectures are mainly intended to aid you in your daily clinical work in correcting the errors of refraction, and, above all, to incite you to earnest study of the more elaborate works on this most interesting subject.

THIRD LECTURE.

EMMETROPIA.

Normal refraction—Visual acuteness—Conjugate foci—Size of image—The test types—Visual angle—Infinity—Distance of testing—Vision better than normal—Test for illiterate persons—Method of recording—Field of vision—Perimeters—Scotomata—Convergence of visual lines—Glasses prescribed.

GENTLEMEN :—As I propose in our lectures to consider only vision and the errors to which it may be subjected, and having explained the various anatomical parts concerned in the sense of sight, also the action of our means of correction, as lenses, etc., as the rays of light pass into the eye through the dioptric apparatus, we will now examine the normal eye in its power to see and appreciate the objects around us.

I shall speak of the normal eye first, though I believe that there are very few persons who have perfectly normal vision even from their birth, although perhaps many of them have had no trouble with their eyes, and have always supposed their sight was equal to that of the perfect standard. This fact was well demonstrated a few years ago by Prof. D. B. St. John Roosa, in an examination of a number of gentlemen, all students, whose ages ranged from twenty-one to thirty-two years, who had never been conscious of any visual weakness, and whose eyes were examined under the influence of atropia, the accommodation being completely at rest. The results of this examination were, that only one fifth, or about 20 per cent., had normal eyes.

My friend, the late Dr. Edward T. Ely, also examined one hundred cases of infants' eyes, with the ophthalmoscope, and found a very small number with normal eyes; nearly all of them having the short eyeball. I should think from this that ametropic eyes, or eyes that are not normal, in reference to their refraction, and do not focus rays of light upon the retina when at rest, exist in the largest number; though they may not suffer from any of the symptoms of asthenopia, or weak sight.

By the normal eye, I mean one that when in a state of rest has its refractive power so adjusted that it can see distinctly, at a remote point or infinity; so that parallel rays of light are brought to an exact focus on the retina, at the macula lutea. This is called the *emmetropic* eye. Landolt says: "The emmetropic eye is one the retina of which is found at the principal focus of its dioptric system, or one which unites parallel rays on its retina, or, expressed in another manner, the punctum remotum of which is situated at infinity." To this I might add, that an emmetropic eye is one whose refractive power is such that rays passing from the retina through the dioptric media pass outward in parallel lines.

Let us test an emmetropic eye, and what will be the results of the examination, as regards the vision at a distance and at the near point? Suppose the $V = \frac{20}{20}$, and the nearest point of distinct vision for the smallest type five inches, the person examined being twenty years of age; in such a case the visual acuteness $= 1$, as the person has distinct vision at infinity with the eye at rest. By visual acuteness, I mean that power of the nervous elements of the eyeball (the retina) to see and appreciate certain objects, as test-letters, at a specified distance, whose standard is $\frac{20}{20} = 1$.

You are probably aware that when rays of light from an object pass through the dioptric media they will be

brought to an exact focus on the retina, and there form a distinct inverted image.

We know that there is an inverted image formed at the focal point of the dioptric system, as the entire refractive apparatus has the same effect on the rays of light, either parallel or divergent, as a simple convex lens. Now the image formed by a convex lens is according to the laws of the conjugate foci, which I will explain to you in this manner: If we pass the divergent rays from a luminous point through a bi-convex lens, they will be refracted and brought back to a point, at the focal distance of the lens. You can readily prove this, and should do so, by using for your luminous point a very small flame; you must also have a screen to receive the rays after they have passed through the lens, and when in their proper positions the rays from the flame will focus on the screen. We can reverse the direction of the rays by placing the luminous point in the position of the screen, and the screen where the flame was, and we find the same focal point of the lens. From this experiment we have two focal points, a first or anterior, and a second or posterior, and these two points are the conjugate foci of each other.

You must remember that when the rays from any illuminated object pass through a bi-convex lens each point on its surface sends off divergent rays, which by the action of a lens are again brought to a point. This point is on the axial ray, which, proceeding from a point, strikes the surface of the lens coincident with the normal, and is not refracted.

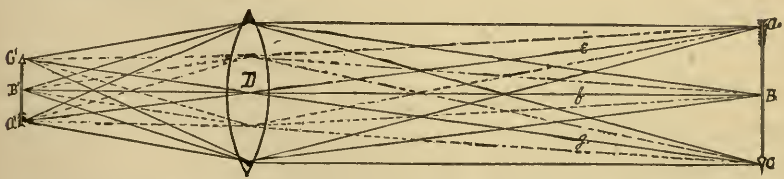


Fig. 25.—The Conjugate Foci of a Bi-convex Lens. The Dotted Lines simply Show the Course of Rays in Other Parts of the Lens.

Now take the course of the rays as they proceed from the three points, *A*, *B*, and *C*, on the large arrow, with the principal axis, *f*, and secondary axes, *e*, *g*. These are the rays from each point that strike the lens perpendicular to its surface, and are not refracted. We also find that all other rays, as they strike the lens on all parts of its surface, from each individual point, pass through, *are* refracted, and brought back to an exact focus upon the same axis from which they started. All the rays from *A* will focus at *A′*, also from *B* at *B′*, and from *C* at *C′*, with each axial ray passing through the nodal point *D*, or optical centre of the lens.

As all these secondary axes must cross the principal axis at the nodal point of the lens, you will readily understand why the image of the arrow is reversed when formed at the focal point. As the rays are refracted the image becomes reversed, and very much diminished in size, according to the distance of the object from the lens.

Should you wish to estimate the size of this retinal image at any time, I will give you a simple rule. If you have the size of the object and its distance from the nodal point, you may then make your calculations in this way: The size of the object added to the distance of the nodal point from the retina, which you will remember equals 15.1501 mm., and divided by the distance of the object from the eye, plus the distance of the nodal point from the cornea, which equals 7.4969 mm., will give us the size of the retinal image.

You can more readily understand how to estimate the size of an image from fig. 26, which not only illustrates the conjugate foci, but also the method of calculating the size of the retinal image. Our formula would be from this diagram: $\frac{A.B + Nc'}{C.E + NE} = a'\,b'$. We would have the same sized image if a smaller object were placed at the position of x or y.

We will not discuss the question why the image being reversed on the retina does not appear so to the observer, as the subject has not been finally settled, and I believe never will be, as it is an act of nature, that we learn from the cradle. When the sensitiveness of the retina is established, when the infant's eye first begins to notice the bright light of a lamp, then the brain sees it inverted, and so it appears through life.

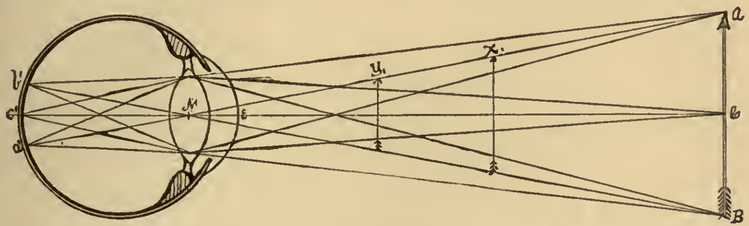


FIG. 26.—THE CONJUGATE FOCI OF THE EYE AND ESTIMATION OF THE SIZE OF RETINAL IMAGE.

Now the percipient elements of the retina may not be developed, perhaps from neglect, congenital causes, or from non-use, and then it will require a much larger image to convey a positive impression to the brain.

If, then, we consider that the visual acuteness of the retina = 1, on what will this fact depend, and how shall we test it ?

I prefer to use the test-types adopted by Snellen, who has selected such letters that the width of each line at the proper distance from the eye will form two opposite points on the retina. These, with the nodal point, subtend an angle of one minute ; the black lines of all these test-letters will make an image of that size (one minute) in its smallest part. Now if we take five lines, or five spaces, for the size of each letter, we will then form an image upon the retina which subtends an angle of exactly five minutes, that being, in a majority of cases, the smallest visual angle and image that the normal retina can appreciate.

To fully understand this visual angle, you will note that if we take the two most opposite points of a test-letter, which should be distinctly seen at twenty feet, and is placed at that distance from the eye, rays of light from these two points, the secondary axes of their conjugate foci, will cross at the optical centre of the dioptric system.

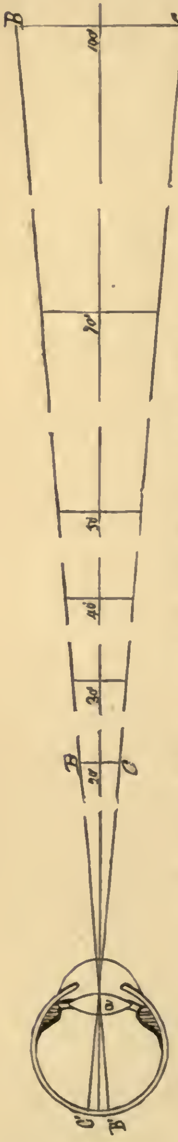


FIG. 27.—THE VISUAL ANGLE, AS FORMED BY SNELLEN'S TEST-TYPES.

This is shown in the drawing by the lines B to B' and C to C', crossing at the nodal point a, and proceeding to the retina. We will then have an angle $aB'C'$, with the base at the retina, and the apex at a, the nodal point. Now the angle, as above, that can usually be formed by a letter is one of 5′, giving an angle of 1′, as that of the several different parts of the letter and its intermediate spaces, this being the smallest image that can be appreciated by the retina. All the larger letters on the test-cards will subtend the same angle when placed at their respective distances, as the largest letter when placed at 200 feet should give the same visual angle as the smaller letters placed at a distance of 20 feet from the eye to be tested; it is also very obvious that we have the same angle with the other letters at 30, 40, or 50 feet. Consequently an eye that can see the smaller letters at 20 feet should also see the larger letters at 30 feet, or the largest letter at 200 feet.

Now you will have observed that I use the fraction to express the degree of visual acuteness whose numerator represents the distance at which the letters were

seen, and whose denominator represents the distance at which the letters should be read. The cards of test-types now in use have different sizes of letters that should be read easily at certain distances, as are marked on each card ; at the same time you will have also seen that they all form an image on the retina whose angle is always the same, that is, an angle of 5′.

Thus No. 20 should be read distinctly at 20 feet, No. 40 at 40 feet, No. 100 at 100 feet, and so on ; but, if we take 20 feet as the standard of infinity, and if at that distance the observer can only see letters that should be seen at 40 feet, V will then equal $\frac{20}{40}$ according to our rule for using fractions, in which the numerator represents the distance of the test, and the denominator the distance at which the letters should be seen distinctly.

Now all rays that come from 20 feet or infinity must be practically parallel ; then if the eye is emmetropic—*i. e.*, adapted for these rays—the letters which should be seen at 20 feet will form a perfect image on the retina. I would advise you to always test your cases at 20 feet, as it is the standard distance, while I think we get better results in our examination of the vision.

You will also meet with some cases that can see better than $\frac{20}{20}$. Their vision is above the normal standard and its acuteness is equal to $\frac{20}{15}$, or even $\frac{20}{10}$, by which I mean that they can read letters at 20 feet that should only be read at 15 or 10 feet ; therefore their vision is above or better than the standard.

You must not be surprised at this, as you will find it the result of examination of the eyes of many young, healthy persons whose dioptric media and nervous elements are perfect. But, some standard must be adopted, and Snellen's test-letters at 20 feet is about the greatest distance for normal vision in the largest number of cases : from this we would expect in all our examinations, if possible,

to make the person examined at least see $\frac{20}{20}$. When you wish to record the results of your examination, take for the acuteness of vision V = the numerator, or distance at which the letters are seen, = d, and for the denominator the distance at which the letters ought to be seen, = D. We have the fraction, $\frac{d}{D}$, which in the normal or emmetropic eye would be $V = \frac{20}{20}$; then, if not up to this standard, we must decide that the visual acuteness is below normal, and you should endeavor to correct it by glasses if possible. Among our patients, particularly at the clinics, we meet persons with diminished sight or weakness of vision, but so illiterate that they cannot read letters. In such cases we use a sign, adopted also by Snellen, in the shape of the letter E, which is square, with one side open and the ends pointing in different directions, as upward, downward, to right or left, as **ш, m, E, Ǝ.** This method is of service also with children and mutes. They are of the same size as the ordinary test-letters, and are recorded in the same way, as $V = \frac{20}{20}$, and so on.

Snellen's test-types are in almost universal use, and I think they are suited for all practical purposes. At the same time you should know that there are other test-types in use in different countries and with different letters, particularly those of Green, Dennett, and Monoyer ; but I do not think they have any practical value over Snellen's.

This is our principal test for the acuteness of vision, and it is not only very simple and practical, but it also gives us a test for all errors of refraction, as I shall show you when we study our cases of ametropia.

In the use of test-types you will remember that the illumination of the letters makes a great difference. It should always be about the same, with a good clear light from a window and the observer placed so that the light will not be unpleasant to the eye. You should also avoid reducing the fractions, in your records of the acuteness of vision : as,

for instance, if $V = \frac{20}{40}, \frac{5}{10}$, or $\frac{1}{2}$, you should record it as $\frac{20}{40}$ only, because the smaller letters may not be seen at the shorter distance, as those for 10 feet may not be seen at 5 feet, and so on. Nor does it give us a true record, while that of $\frac{20}{40}$ shows exactly the distance at which the person was tested and the smallest letters that could be read at that distance. If you use the distance of 16 feet for your test, or infinity, then the numerator will be in all cases 16, and $V = \frac{16}{40}, \frac{16}{16}$, etc.

If we find that in the emmetropic eye $V = \frac{20}{20}$ or less, we should examine the sensibility of the retina, not only at the macula, but in all the peripheral parts. Although in these eccentric portions V does not equal $\frac{20}{20}$, still we should know that the perceptive elements are in a normal condition, and that the sensibility of the retina is not deficient in any of its parts. The power to see with the peripheral portions may be diminished by some pathological conditions, as in glaucoma, partial detached retina, etc.

For this examination the most simple manner of test is to sit in front of the person to be examined, and as you cover one eye, direct the patient to look at your own eye, at a distance of about two feet; then keeping the optic axis of the examined eye directly forward, you will hold the hand or a pencil at different positions around and in front of the eye, and as far away as possible. The farthest point at which the finger or pencil can be seen will give the *quantitative*, and the distance at which the fingers can be counted will give the *qualitative*, field of vision. If you use your right eye at the same time you test the left eye of your patient, and hold the finger or pencil just between the eyes, you can compare the field of your eye with the examined eye.

Another good method is to place the person to be examined before a blackboard, at a distance of about twelve

inches, and with one eye covered, direct him to look steadily with the eye to be examined upon a small mark directly opposite the eye. A piece of chalk held in the hand is then to be carried along the surface of the board, from its outer edge towards the centre, on a vertical or horizontal line, until it can be seen simply as a white object: make a mark at this point. You will then proceed to test all the other meridians of the blackboard, with the mark as a centre, and place a mark at each point where the chalk is first observed.

FIG. 27*a*.—EMERSON'S PERIMETER.

This record can be easily transferred to a small sheet of paper, by drawing the centre and the various marks in their respective positions. Then measure the distance in inches from the centre mark outward on each meridian, and a line drawn to connect each mark will give the size and shape of the visual field.

An excellent instrument, called the *perimeter*, has been devised for testing the field of vision. Invented, I believe, by Förster, also by Carmalt of New Haven, and by Dr. J. H. Emerson of this city. I prefer Emerson's, as I think it is the most perfect and simple. This perimeter consists of a brass stand, with an upright, and an arm one fourth of a circle; at the end of this arm there is a half circle of brass, which is moved on the smaller arc by a pivot in the centre; in this there is an opening, through which the person examined must constantly look. This arc of a circle is graduated in degrees, and can be placed to correspond

with any of the meridians of the eye. A small upright extends from the stand for the chin to rest upon, which brings the eye exactly on a level with, and in front of, the opening in the arc. There is also a slide, moving freely on the arc, from end to end, on which is placed a small disc of white paper. Then, with the person to be examined in the proper position, you will make your tests by moving the slide on the arc toward the centre until the disc can be seen.

This test will give you the quantitative field, while a small letter placed on the disc, and used in the same way, will give you the qualitative field.

This instrument is small, compact, and very useful, as, by changing the white disc of paper to one of any other color, we can test the field for its power to distinguish colors in all the peripheral parts of the retina. You will find that the normal field varies in size for the different colors, as that for white being the largest, blue next, then red, and that for green the smallest.

After you have mapped out the extreme limits of the field of vision with the perimeter, you should slowly carry the slide with the disc completely up to the centre. If the white disc should disappear, or become blurred at any time, you must carefully record all the points at which the blurring commenced, and also the points where it becomes clear again, as it is carried toward and to the centre. When you have examined all the meridians and completed your test, you may find that a certain portion of the retina has lost its sensibility to rays of light, though the functions may be perfect all around this deficient portion. In this manner we map out on our diagram any spots of deficient vision on the retina, as *scotomata*, or blind spots, from any cause, as retinal hemorrhages, etc.

I would here particularly wish to caution you not to mistake the normal *blind spot*, the entrance of the optic

nerve, called the *punctum cæcum*, or *Mariotte's* blind spot, for one of any pathological significance. There are no perceptive elements at this point; vision is absolutely nothing. The nerve entrance lies a short distance inside of the macula, a little below the horizontal meridian. It will be found in the field of vision on the opposite side, about 15° outward and 3° below the point of fixation.

Although this blind spot is so easily marked out with the perimeter, you must remember that it is very small, and in binocular vision, as the rays from any luminous point enter each eye, they fall upon different regions of each retina, conseqnently one eye will supply any deficiency of vision, from the rays falling upon the optic-nerve entrance of the other eye.

You will find with the perimeter certain charts that are excellent for recording the extent of the field. As they are marked to show the size of the normal field and the optic-nerve entrance, you can readily record the results of your examination. By them, if taken at different times, you can tell whether the field is still contracting, becoming larger, or of the existence and extent of any scotomata in the field of vision.

In the use of the perimeter we can place the arc of the circle at any meridian we wish to test. It is readily movable on the centre, while at the apex there is a dial with a pointer, which marks the meridian at which the arc stands. In using your test, either with the white or colored discs, letters, or figures, these should be moved from the periphery of the arc toward the centre. The markings in degrees, on the back of the arc, will show you the point at which the white disc is seen. Generally, we examine the eyes in four meridians, as the vertical, horizontal, and the two intermediate meridians, or at 45° and 135°. But you may examine any number of meridians that you may think necessary to make your test complete.

As you test each meridian, the other eye being covered with a screen, the point at which the disc is seen should be marked on the chart. Now draw a line from each mark, and you will have the extent and shape of the field of vision. The usual extent of the visual field will be found about 90° outward, 50° inward, 65° downward, and 45° upward. Should there be any spots on the retina, as scotomata, they will be marked out in the same way, when the test is carried inward to the centre. The reason we find the field limited on the upper and inner part, is because of the projection of the cranial bones, as the superior edge of the orbit and the bridge of the nose.

You will also note that, should any contraction of the field of vision be shown by the charts, it is the opposite side of the retina that is affected, the outer part of the field, as shown by the charts, representing the inner part of the retina. Now, should the outer half of the field be blind, this is *hemianopsia*, which would represent the inner half of the retina as being affected, or *hemiopia*. The blindness may be in the upper or the lower part of the field, as the tests may show. You would then have the opposite parts of the retina affected respectively.

The emmetropic eye will not require glasses, either for distant vision or for work at near distances, as long as the power of accommodation and convergence is sufficient; but in case of failure of the power of the ciliary muscle, our involuntary muscle of accommodation, or of the voluntary muscle of adduction, the internal recti, the eyes will require external aids to vision. Or, we may go still further, and include the negative part of convergence, according to Landolt, of Paris—that is, the power of abduction by the action of the external-recti muscles. You must remember that the visual line is fixed upon the object, not only by the action of the internal recti, but also by the controlling antagonistic muscles, the external recti; so you

can realize that, if these abducting muscles are too weak, they also will tire in the efforts to correct the convergence of their antagonistic muscles.

We therefore find that, though the emmetropic eye may be a perfect eye in its refractive power, to so bend parallel rays of light that they will focus upon the retina when the eye is at rest, yet, if we keep up a constant strain upon the muscular power when the eyes are at work for near vision, we must have a certain power of accommodation; also a perfect equilibrium between the muscles of adduction and abduction. In case these are deficient, we must use convex glasses to relieve the strain upon the muscle of accommodation; and prisms to relieve the strain on the internal- or external-recti muscles.

We will consider this more fully under the subject of accommodation and the use of prisms, with the method of testing the eyes for those most important symptoms of asthenopia occurring in the emmetropic eye.

FOURTH LECTURE.

HYPERMETROPIA.

Hyperopia—Refraction—Direction of rays—Vision of—To record—Causes of—Manifest—Action of ciliary muscle—Latent or concealed—Total—Facultative—Relative, Squint and causes—Primary and secondary deviation—Absolute—The punctum remotum of—Axial hypermetropia—Glasses to be ordered.

Gentlemen :—As the normal or emmetropic eye is, when at rest, perfectly adapted to focus parallel rays upon its retina, there forming a perfect inverted image, let us now study the refraction of an eye that is *ametropic*, or one that will not focus such rays when its accommodation is at rest,—one whose retina is not situated at the focal point of the dioptric apparatus.

I am inclined to believe that the majority of eyes that exist in nature are not emmetropic, but that when the muscular system of the eye is at rest the rays of light from infinity strike the retina before they have come to a focal point, and thus the images formed become blurred and indistinct. Such an eye is called *hypermetropic*, and the condition of refraction *hyperopia;* but these terms are interchangeable. The rays passing from the retina outward through the same refracting media, and having the same angle of refraction as the emmetropic eye, but coming from a point nearer to the refracting surfaces, will pass from the cornea outward in a divergent direction. I would therefore class the hypermetropic eye as one whose optic axis is shorter than the normal, or one in which parallel rays are focused behind the retina, and the emergent rays are divergent when the eye is in a state of rest.

This condition, in which we have a positive shortening of the antero-posterior diameter of the eye, is called *axial* hypermetropia. You will find it to exist in the majority of those cases you will examine. But you may also find that the power of the refracting surfaces is not as great as in the normal eye, so that the optic axis may be of normal length; but the curvature of the cornea or lens being less than that of the normal eye, the parallel rays will not focus until they have passed behind the retina. This condition is known as *refractive* hypermetropia. You will find it very difficult to prove that the refractive power is too low, while the diagnosis and correction are the same; and for the purpose of simplifying our study of this refractive condition, we will only consider that variety in which the optic axis is too short.

Now the hypermetropic eye can generally see as well at a distance as the emmetropic eye, but to do this it must, by the action of the accommodation, so bend parallel rays of light that they will exactly focus upon the retina.

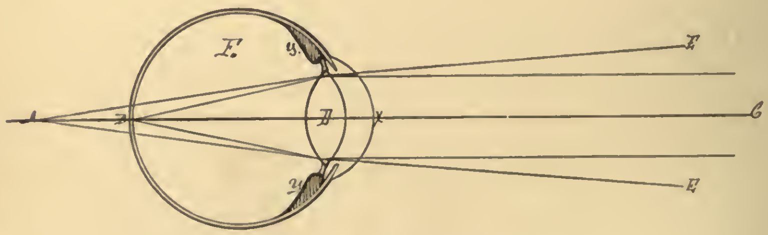


FIG. 28.—DIAGRAM OF THE HYPERMETROPIC EYE.

This diagram represents an eyeball whose optic axis is shorter than the emmetropic eye, as from *X* to *B*; the parallel rays coming from infinity at *C* focus at *A*, behind the retina; but when the ciliary muscle *Y* contracts, and the refractive power of the crystalline lens *D* is increased, the parallel rays are then focused at *B*, or exactly upon the retina. If we place a bi-convex glass in front of

the eye, it will have the same effect to focus the rays of light with the eye at rest, and this glass will represent the amount of hypermetropia present.

If we follow the course of the rays of light as they proceed from the retina at *B*, taking the region of the macula as the source of illumination, the rays as they pass outward through the same media, having the same refractive angle as the rays passing inward, will take a *divergent* direction as they leave the cornea, and will proceed in the direction of the lines *E*, *E*. I wish to impress this upon you, because, when you estimate the degree of hypermetropia with the ophthalmoscope by the direct method, you must consider the direction of these emergent rays. A convex glass that will render them parallel will represent the amount of hypermetropia.

Let me illustrate this by an example of a hypermetropic eye at rest when tested by Snellen's test-type. The eye can only appreciate the large letters about $\frac{20}{100}$, but if we now place before the eye a convex lens of 20 inches focal distance, or 2 D, the vision at once becomes $\frac{20}{20}$, or normal. Hence we see that the hypermetropic eye is adapted for convergent rays, because the rays after passing through the lens are rendered convergent, and then exactly focus upon the retina.

If in place of the convex lens the eye employs a portion of its accommodative power, the $V = \frac{20}{20}$. In a second case the vision may be $\frac{20}{20}$, and still remain the same, if we place a convex lens before the eye; so that we have normal vision either with or without a convex lens. This latter is called *manifest* hypermetropia, and the strongest convex glass through which vision still remains, $\frac{20}{20}$, will represent the amount of manifest hypermetropia (Hm.). We would then record this condition of refraction as follows: $V=\frac{20}{20}$, Hm. $\frac{1}{40}$; that is to say, the $V=\frac{20}{20}$, and is still the same when a convex glass of 40 inches focal distance is placed before the eye.

As regards the cause of hypermetropia, I think I have shown, in my remarks upon the emmetropic eye, that this "flat formation," or plathymorphia, is congenital, and in some cases hereditary. You will remember as the results of the examinations made by the late Dr. E. T. Ely on a large number of children, that they were mostly hyperopic. I will not endeavor to explain those cases in which the refractive power of the dioptric apparatus may be too low, nor those cases in which a portion of the refractive apparatus may have been removed, as after cataract operation; but while I shall at some other time refer to the cases in which there is a failure of the accommodative power, we will now simply study the eye as an optical instrument whose focal distance is too short.

We look at the hypermetropic eye as one whose optic axis is too short, and in which parallel rays will focus behind the retina, so that, impinging upon the retina, before they have reached a focal point, they will there form circles of diffusion, causing reduced vision. But does the hypermetrope suffer from the reduced vision? No; because from the action of the ciliary muscle the refractive power of the eye is increased, and vision becomes perfect.

We divide hypermetropia into different degrees, according to the condition of the accommodative power of the eye. This I will illustrate to you by some simple examples:

A patient reads $\frac{20}{20}$, V = 1. Then if we place a convex spherical glass before the eye, and vision remains the same $\frac{20}{20}$, then the strongest convex glass,—say $+\frac{1}{36}$—that will be accepted without diminishing vision, will represent his *manifest* hypermetropia, which I have shown you how to record. If we try $\frac{1}{30}$ and find the vision worse, we may then conclude that the amount of error of refraction is at least equal to a glass of 36 inches focal distance. But does this equal the whole amount of hypermetropia?

No; because a certain amount will be *latent* or *concealed* from the action of the ciliary muscle, the patient not being able to completely relax it. We must then stop the action of this muscle by some mydriatic, the best of which is the solution of the sulphate of atropia (4 grs. to an ounce) dropped in the eye several times, as three times a day, for two days. Now we will find that the vision is very much reduced, as the eye cannot focus the rays of light upon the retina then the strongest convex glass that will make the vision equal $\frac{20}{20}$, will represent his *total* hypermetropia. We now find that the record stands $V = \frac{20}{100}$, with $+\frac{1}{12} = \frac{20}{20}$, so that a convex glass of 12 inches focal distance represents the amount of total hypermetropia. This glass also shows you the amount of convexity that is added to the crystalline lens by the action of the ciliary muscle, in causing the parallel rays of light to focus upon the retina.

From our illustrative case we may conclude that the manifest hypermetropia was equal to $\frac{1}{36}$, and that the total was equal to $\frac{1}{12}$, so that the latent hypermetropia, or the amount that was concealed until we used the solution of atropia, was equal to $(+\frac{1}{12}) - (+\frac{1}{36}) = +\frac{1}{18}$. This latent error of refraction is necessary in some cases to be estimated, particularly in young persons. Although the manifest amount is most important, the latent will show us just how far we may go in making the glasses for distant vision stronger; at the same time it gives us a correct record of the total error of refraction.

The term *facultative* hypermetropia is used by some oculists, the meaning of which I interpret as the faculty or power of the eye to see well at a distance, either with or without a convex glass; so that it has about the same meaning as manifest hypermetropia. This expression I consider much more correct, because the error of refraction is manifest, and no other conditions of the eye will

accept a convex glass and still have V = $\frac{20}{20}$, or 1. Landolt calls this condition *facultative relative* hypermetropia.

All hypermetropes require a certain amount of accommodation to see clearly, which is very great in high degrees, and it has been proven that we can exert a greater power of the ciliary muscle when acting in conjunction with the internal recti. You will notice some hypermetropes that can only see clearly by converging the visual axes to a point much nearer than the object. By this means they gain clear vision at the near point, but at the expense of their binocular vision. When an object is brought up to a point six inches from the eyes, the visual lines are converged to a point at three inches. This condition is called *relative* hypermetropia, from the close relation that exists between the ciliary muscle and the internal rectus.

You will find this condition in persons who have convergent strabismus, or squint. From early childhood, when they first begin to use the eyes, they soon learn that they can improve the vision by squinting; and, although the mother may give you a history of some spasm, accident, etc., that occurred to the child about the same time, and to which she will attribute the cause of the strabismus, yet, when you examine the eyes and find a certain degree of hypermetropia, you may feel sure that the refractive condition was congenital, and that the strabismus has been acquired to enable the child to see its playthings clearly.

At first, they will not have the squint constantly, but it will always be observed when the child looks at near objects, and occasionally when looking at a distance. This condition is then called *periodic* strabismus, and can sometimes be relieved and corrected by the use of a properly selected glass. If not corrected, the strabismus may become permanent and the vision of the squinting eye very

much reduced. The image formed upon the retina at the macula lutea has been suppressed for so long that the eye becomes *amblyopic*, without any obvious condition to account for the reduced vision. After the convergent squint has become permanent, it can only be relieved by a tenotomy of the internal rectus, and then correction of the hypermetropia with glasses.

I am inclined to think at the present time, in many of the cases of squint with hypermetropia, in which we find one eye very amblyopic, that probably there is either a deficiency of the retinal elements in that eye or a non-development of the retina. This is usually of congenital origin I believe, and not from non-use, as supposed. The child or grown person has never been able to fix the vision with the squinting eye. The eyes have converged to attain a larger amount of accommodation, and to enable the eye with a fully developed retina to see clearly. From this congenital defect in vision the amblyopic eye has no stimulus to fix the rays of light from the object upon the macula lutea, and so to keep the visual lines parallel when looking at a distance ; and as the internal rectus muscle has the greatest power of all the external muscles of the eye, it overcomes the action of its antagonist, and consequently the eyeball turns inward with convergent strabismus established.

This deviation of the visual line does not cause any annoying diplopia, or double vision, because the squinting eye is amblyopic, and the retinal image of that eye is very indistinct, consequently there is no stimulation to bring the rays of light upon the macula.

The direction of the visual line of a squinting eye from that of the normal is called the *primary deviation ;* while, if the perfect eye is covered, so as to force the squinting eye to fix its visual line upon the object, we now have a deviation of the covered eye of the same degree

as that of the other. This is called the *secondary deviation;* or, in other words, the squint is transferred to the sound eye. Yet, as soon as the eyes are uncovered, they at once resume the primary deviation.

Let us now consider the eye that cannot control those parallel rays, or which has lost its power to bring them to a focus upon the retina. This condition generally occurs as the patient nears the age of forty years, but may occur earlier. Now the hypermetropia is positive, and for this condition we use the term *absolute.* Let me illustrate this to you by a case that cannot see the small letters at 20 feet. When looking at infinity, the accommodative power is too weak to focus the parallel rays upon the retina, consequently they impinge upon the retina before they have come to a focus, and there form circles of diffusion, requiring a much larger image to appreciate the letters. Then we find that $V = \frac{20}{100}$, and the patient is unable to see clearly at a distance. If we find that the patient's $V = \frac{20}{100}$, then the strongest convex glass that will give the best vision will represent the *absolute* hypermetropia, as $V = \frac{20}{100}$, with $+ \frac{1}{12} = \frac{20}{20}$.

We have now, perhaps, slight latent hypermetropia, but the refractive error is at once shown and is positive; while the amount of error is represented by the strongest convex glass that will give the best vision, which should equal $\frac{20}{20}$. Landolt calls this the *absolute manifest* hypermetropia, as there is always a certain amount latent.

This condition you will seldom meet with in young people, but generally in persons who have passed the meridian of life. Their power of accommodation is so reduced that the eye cannot focus parallel rays of light on the retina.

You will find some cases of hypermetropia that will not accept any convex glass—that is, their vision $= \frac{20}{20}$, but all convex glasses will blur. Yet we know that the eye

is hypermetropic from the examination with the ophthalmoscope. The reason of this is because they have been accustomed to use a certain amount of accommodation when looking at distant objects; consequently, when the convex glass is placed before the eye, they are not able to relax the ciliary muscle. With the convex glass the rays are rendered too convergent, and the vision is blurred.

In such cases the total hypermetropia is all latent, and can only be demonstrated by the use of atropine, after the condition of refraction has been determined with the ophthalmoscope. You will frequently find this in young persons, but in my examinations I often make them accept the convex glass, by putting a glass over each eye, allowing binocular vision, when the accommodation will relax much more readily.

In the emmetropic eye we have shown that its refraction was adapted for parallel rays when at rest, consequently its *punctum remotum*, or distant point of distinct vision, would lie at infinity; but in the hypermetropic eye parallel rays will focus behind the retina in all cases, as the optic axis is too short. This is the *axial* hypermetropia of Prof. Landolt, and the eye will require convergent rays to focus on the retina. We have no convergent rays in nature,—they are parallel or divergent; so the punctum remotum of the hypermetropic eye will lie behind the retina, at the focal point of the convergent rays (see A, fig. 28) to which the eye is adapted, and the punctum remotum becomes *negative*.

This negative point can be found by the focal distance of the convex glass that will correct the total hypermetropia, less the distance of the glass from the nodal point of the eye. For example, if the total amount of hypermetropia be equal to a convex glass of 12 inches focal distance, and the lens be one inch in front of the nodal point, *then* the punctum remotum will lie at 11 inches be-

hind the nodal point, which you remember is near the posterior surface of the lens of the eye. The eye is adapted for convergent rays, whose lines will intersect at the punctum remotum. When the hyperopic eye is at rest the rays must have this convergent direction to focus on the retina, and it consequently requires a part of its accommodation to see parallel rays.

If we illuminate the fundus of the hypermetropic eye, there will be certain rays that are reflected and pass outward. These rays will pass in exactly the same direction as rays that focus upon the retina must take when passing inward, as their course is through the same refractive media. Now as we have shown that the eye is only adapted for convergent rays, consequently the rays passing outward from the retina will be divergent (see *E*,*E*, fig. 28). They will require a convex glass, equal to the amount of total hypermetropia, to render them parallel, or the same as those passing from the emmetropic eye.

As I have stated that this fact is important in the diagnosis of hypermetropia with the ophthalmoscope, I must refer you to the lecture on that instrument for the method by which you may estimate the total hypermetropia in all cases.

Having now determined the amount of hypermetropia in any case under our care, the question arises: What glasses shall we order for this error of refraction? I have found generally that in young persons it is only necessary to correct the manifest hypermetropia, and I would therefore order the strongest convex glass that they will accept and still have perfect vision, or the same vision that they have without glasses.

These glasses should be worn constantly for a short time, and then for reading and other close work. In those cases where the ciliary muscle is too weak, and the hypermetropia becomes absolute, you will then order the strong-

est convex glass that will make the vision $= \frac{20}{20}$, and have this glass worn constantly, for both near and distant vision. When they have passed that age when the ciliary muscle becomes too weak for near vision with the glass that corrects the hypermetropia, then they will require a stronger glass for reading and all near work.

FIFTH LECTURE.

MYOPIA.

Axis too long—The myopic eye—Axial myopia—Other causes than axial—Increased curvature of the cornea—Commencing cataract—Congenital or acquired—Causes and production of—Progressive, with posterior staphyloma—Diagnosis—With glasses—Its punctum remotum—Emergent rays—Glasses to be ordered—Accommodative, or spasm of ciliary muscle—Treatment of spasm.

GENTLEMEN :—We have demonstrated in our previous lecture that the eyeball may not have been fully developed, and in which the optic axis was too short. Now we may have just the reverse of this condition, and the eyeball will be too long; *i. e.*, the optic axis will be longer than that of the normal eye. This condition is called *myopia*, or short-sightedness.

With the optic axis too long, the rays of light passing through the same dioptric media as those of the emmetropic eye, you will see that the entering rays must come to a focus before they reach the retina, and, crossing, they will strike the retina in a divergent direction. They will there form circles of diffusion, and the images on the retina will be indistinct. Then those rays passing from the retina, coming from a point farther removed from the refractive surfaces, but having the *same* refractive angle, will pass out of the eye in a *convergent* direction.

I would therefore class the myopic eye as one whose optic axis is longer than that of the normal eye, or one in which parallel rays will focus in front of the retina, and the emergent rays are always convergent.

You will find that this condition exists in nearly all cases of myopia. But there are other conditions that

may cause it. The refractive power of the dioptric apparatus may be too strong, due to an increase in the normal curvature of the cornea or lens. The eyeball may be of the normal length, but owing to the increase in the refractive power the rays will focus in front of the retina.

Another remote cause you will sometimes see in the first stages of cataract, as a person will then become myopic or shortsighted, though the eyes had always hitherto been normal for distant vision. This is due to the changes that are taking place in the crystalline lens, causing an increase in its size; consequently, as the curvature is greater, so is the amount of refraction.

But in the large majority of cases you will find that there is an actual increase in the length of the optic axis; so much so that you will notice it in the protruding eyes of some patients, with somewhat restricted movements of the eyeballs. This condition is called by LANDOLT *axial* myopia,—an excellent term in contradistinction to the myopia caused by an increase in the power of refraction.

I prefer that we should study the various conditions of ametropia principally from the length of the optic axis, whether too long or too short, as it will simplify the study of refraction, while we will be able to appreciate the course of the rays of light as they pass inward or outward from the eyeball much more easily.

Myopia is either congenital or acquired, as the case may be, though I believe that there are very few persons born myopic except those who may inherit it. While in the acquired form, as you will find in many students, I think it is due to the constant straining and congestion of the eye, produced by the dependent position of the head when a person is leaning forward to read; also from the constant pressure that is exerted upon the sides of the globe by the normal tension of the ocular muscles.

LANDOLT, in his excellent work on refraction, has advanced the theory that in many cases the eye is first affected with a disease, such as choroiditis posterior, thereby causing a weakness of the tissues in the region of the macula. This may lead to posterior staphyloma, retinal hemorrhages, changes at the macula, and detachment of the retina. But I am inclined to think that the condition of myopia previously existed, and, by the efforts to see clearly, the existing pathological condition was developed, causing an increase in the myopia. Where we have this increase in the myopia and the process still active we will designate it as *progressive* myopia, which may occur in an eye that was at first perhaps emmetropic or hypermetropic.

We would then have three causes for the production of the myopic eye: First, congenital; second, the hyperæmia, or congestion from the faulty position of the head in reading and study. This condition tends to weaken the tissues of the eyeball, which are also acted upon by the constant drawing forward of the choroidal coat by the fibres of the ciliary muscle. Third, by the constant intraocular pressure, aided by the pressure of the four recti muscles, upon the outer portions of the globe. This pressure is said by Landolt to be so great that by delicate manipulation you may feel the depressions in the globe beneath the course of the internal and external recti muscles. I believe also that this pressure is due to the constant tension produced by the tonicity of all the recti muscles: as this is exerted upon all parts of the equator of the globe, it must cause it to give way, and form an ectasia at the weakest point. This point we find at the posterior pole, perhaps already weakened by the constant congestion from the stooping position, or from a low degree of posterior sclero-choroiditis, and also because this portion of the globe is only supported by the cushion

of fat behind it, while it is deprived anatomically of the support of the connective tissue of Tenon's capsule.

These last conditions existing in an advanced degree give rise to progressive myopia that may be decidedly pernicious in its results, as you will find the myopia constantly increasing, until the vision becomes practically useless.

Now, how will you determine that you have a case of myopia? First, the myope cannot bring parallel rays to a focus upon the retina by any effort at action of the accommodative muscle, because when the eye is at rest, and the ciliary muscle fully relaxed, with the dioptric media the same as in the emmetropic eye, then parallel rays, as they enter and are refracted, will come to a focus in front of the retina. There diverging, they strike the retina beyond the focal point, forming images in circles of diffusion. We cannot reduce the refraction by any act of accommodation, or make the lens flatter than normal. We must then infer that in all cases the myopic eye cannot see clearly at a distance, and that the eye is not adapted for parallel rays.

Let us now resort to Snellen's test. We find the smallest type that the eye can see clearly,—say $\frac{20}{100}$—then place a concave glass before it, using the weakest one that will make the vision equal $\frac{20}{20}$, the number of the glass—say $\frac{1}{10}$—will show the amount of myopia, which you will record in this manner: $V = \frac{20}{100}$, with $-\frac{1}{10} = \frac{20}{20}$.

Let us now try the vision for reading, using the finest type and the longest distance, or the punctum remotum. We find that the patient can read No. 1 of Jaeger's type at ten inches from the eye. Now we know that a concave glass diverges rays of light, as if they came from the (negative) focal point of the glass. So we find that for distant vision we must direct the rays of light as if they came from the most remote point of distinct vision with-

out a glass—*i. e.*, the eye is adapted for rays from a point ten inches in front, and parallel rays must pass as if they came from that point, when they will focus upon the retina.

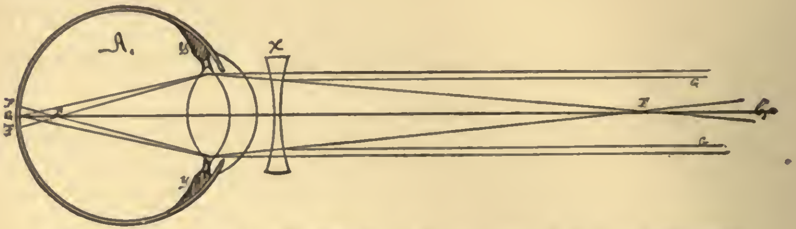


FIG. 29.—DIAGRAM OF THE MYOPIC EYE AND THE PUNCTUM REMOTUM.

If we represent the myopic eye by this diagram, as at *A*, we will see that the parallel rays, from infinity at *C*, are brought to a focus at *B* before they reach the retina; when they reach the retina they will form circles of diffusion at *F F*. But with the concave glass *x* placed before the eye, we now find that the rays, having been rendered divergent as if they came from the point *E*, the punctum remotum, are now exactly focused upon the retina at the point *G*.

We find the same direction of the rays of light when the glass is removed and the smallest test-type of Jaeger is placed at the point *E*, ten inches in front of the eye, as shown by the lines. The rays passing divergently from the point *E*, and through the refractive media, focus upon the retina at *G*. We can therefore decide that the amount of myopia is shown by the weakest glass that will give the best vision at twenty feet; or the greatest distance at which, in inches, the smallest type can be read.

In your trial by glasses you must always select the weakest glass that will give the best vision; for, if you take one of greater divergent power, you will simply call the accommodation into play, and as the rays are rendered more divergent the ciliary muscle will contract, and we still have an exact focus upon the retina.

Having seen that the myopic eye is adapted for divergent rays, if now the eyeball be illuminated, in what direction will the return rays of light pass outward? If we still assume that our dioptric media is exactly the same as in the emmetropic eye, then if the rays proceed from a point beyond the focal distance, and pass outward through the same refractive media, they have the same refractive angle, and must become convergent. They will then focus at the same point that represents the total myopia, which, in the illustrative case, would be at ten inches in front of the eye. This is shown in the diagram, fig. 29, in which the rays of light, reflected from *G* and passing outward, focus at *E*.

The myopic eye is said to be the only object in nature that gives off convergent rays; all others, as you know, being divergent. The hypermetropic eye is the only one, when at rest, that is so adapted, or which can adapt its refraction to these convergent rays of light. Now if the hypermetrope will place his eye so as to receive the rays coming from the myopic eye, then they will focus upon his retina (see Lecture on Ophthalmoscopy).

This is a very interesting fact, and should the degree of ametropia be the same in the eye of the hypermetrope as in that of the myope, each will be able to see the fundus without any glass, and the degree of refraction in one eye will represent that of the other. In making this estimation we must calculate the distance of the observer's eye from that of the observed eye, and that distance should be added to the amount of hypermetropia of the observer, provided his accommodation is at rest.

The next question for us to consider is this: How shall we order suitable glasses for cases of myopia where there is simply an elongation of the optic axis, without any rapid increase in the ametropia? This will depend upon the amount of error of refraction. In low degrees of

myopia, when the vision equals $\frac{20}{20}$, with a glass of twenty inches focal distance (2 dioptries), or less, the patient will need a glass only for distant vision. The remote point for distinct vision for the smallest type is at a distance of twenty inches or more; consequently, by the act of accommodation, the vision will be perfect at any nearer point up to the punctum proximum.

Then if we find that the myopia is of a higher degree, as 4 dioptries (ten inches), your patients will now need glasses, not only for the distant vision, but also for reading. Without a glass they must bring all type very close to the eye, that the letters may be within the punctum remotum.

In such cases I should order the glasses that correct the myopia at infinity to be worn all the time. At the reading distance the glasses will only cause an increased effort of the accommodation without increased convergence, and consequently less external pressure on the eyeballs by the ocular muscles.

That these glasses cannot possibly do any harm has been well proven in an excellent article by Förster in the "Archives of Ophthalmology," where he has noted the effects on the eyes of a large number of persons who had been wearing glasses, over-correcting their existing axial myopia. Nor will these glasses cause the myopia to be progressive, or produce the condition of posterior staphyloma, from any increased tension on the choroid. At the same time you must order the weakest glass that will make vision perfect at infinity, as too much over-correction may cause symptoms of accommodative asthenopia.

From the above facts I believe there is a desire on the part of some oculists to fully correct the higher degrees of myopia, as of 12 to 15 dioptries; but I prefer, in the higher degrees, to endeavor to fit the glasses according to the distance at which the persons desire to see clearly.

Let me illustrate this to you by a case in which $\frac{1}{4}$ (10 dioptries) is required to make the vision equal $\frac{20}{20}$. With this glass, and the type at the near point or ordinary reading distance, as the rays of light pass through this strong concave glass they will be so divergent that it will require a severe effort of the accommodation to focus the rays upon the retina. It would then be advisable to order a much weaker glass for reading. In the myopic eye we find very few circular fibres in the ciliary muscle, and, consequently, very much diminished accommodative power. (See fig. 10.) It cannot stand the strain on the ciliary muscle when wearing the glass that corrects its total myopia, and so should have a weaker glass for reading or music.

The question is often asked : Is not the myopic eye of about 3 D the best eye for general use through life, for the reason that in such a case glasses will not be needed as old age comes on, and the condition of presbyopia will not occur? I should answer that question in the negative. I am inclined to think that, although a myope of 3 D will not need a convex glass to assist his vision at the near point when presbyopia begins, the refraction of his eye being adapted for divergent rays of light coming from a point at its punctum remotum, yet he must always wear glasses for distant vision, while the emmetrope will need a glass only for reading. After the latter has passed the age of forty years, his distant vision remains perfect until very advanced age.

In those cases where we have the myopic crescent, or posterior staphyloma, so frequently seen in the myopic eye, we may leave that condition to pathology and the diseases of the eye. But I would say, when you find this condition extensively exists, that it is due to a low grade of choroiditis at the fundus, extending toward the temporal side. In high degrees of progressive myo-

pia this staphyloma is very large, extending to the temporal side of the disc one or more diameters. This crescent can be seen very perfectly by the indirect method of examination with the ophthalmoscope. By the direct method the image is so large that only a portion can be seen at a time. These cases will require glasses fitted in the same way as in the healthy eye, but the vision is always very much reduced from the changes that have occurred at the region of the macula.

ACCOMMODATIVE MYOPIA.

There is a very interesting condition of the eyes that may exist in any case of ametropia, or even in emmetropia,—a condition of *apparent* myopia, which you must look for in all cases of asthenopia, and which you should guard against, as, if not relieved by proper treatment, it will make the vision much worse and increase the asthenopia. I refer to the condition of accommodative myopia, so called because true myopia may be entirely absent, and the axis of the eyeball even too short or normal. This condition of refraction is generally caused by an over-strain of the eyes while at any continuous work; the ciliary muscle is kept in a constant state of tension until a condition of *clonic* or even *tonic* spasm exists, whenever the vision is used for near or distant sight.

When the ciliary muscle contracts we have an increase in the refractive power of the crystalline lens, so you will readily see that, if the rays are converged by the action of the lens before they reach the retina, you will have the same condition of refraction as in axial myopia, although the axis of the eyeball may be too short (hypermetropia), or normal (emmetropia), while even the myopic eye may be so affected.

We may illustrate this spasm of the accommodation by the diagram, fig. 30, in which *A* represents the eye-

ball (normal), when, if the accommodation is at rest, we find that parallel rays of light coming from *B* will focus upon the retina at *F*. But if we have a clonic spasm of the circular fibres of the ciliary muscle *y y*, with relaxation of the zone of Zinn and increased curvature of the anterior portions of the lens, changing it to *D*, we then have an increase in the refractive power of the dioptric apparatus; consequently the parallel rays will now focus at the point *E* before they have reached the retina, and passing onward will form circles of diffusion at *H H* upon the retina, giving us the condition known as accommodative myopia.

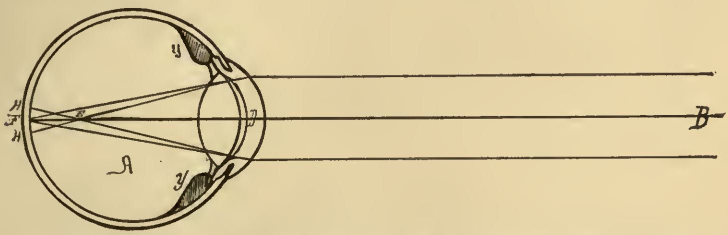


FIG. 30.—DIAGRAM ILLUSTRATING SPASM OF THE ACCOMMODATION.

Owing to this increase in the refractive power of the lens by the spasm of the ciliary muscle the refraction becomes practically myopic, and is adapted for divergent rays; but, when the ciliary muscle is relaxed, emergent rays will pass outward, according to the condition of axial ametropia or emmetropia that may be present.

This condition usually occurs from overwork, and is about the same in each eye, with all the symptoms of asthenopia, as pain and discomfort in and around the eyes.

As the clonic spasm of the ciliary muscle exists whenever the eyes are used for distant as well as for near vision, you will notice that the distant vision is very much reduced, that it will not be improved by convex glasses, and that it will be *almost* normal when a concave glass is placed before the eye. The myope will require a

concave glass stronger than the positive condition of axial myopia that may be present. You will also notice that the region of accommodation is diminished; but on examination with the ophthalmoscope the true refraction of the eye is found. This may be emmetropic, hypermetropic, or of a much less degree of myopia, than is shown by the weakest glass that gives the best vision.

In the treatment of this condition you must use a strong solution of atropine (4 grs. to the ounce) infused into the eye three times a day, until all the symptoms of spasm have disappeared and the trial by glasses agrees with the examination by the ophthalmoscope and retinoscopy. Then cause your patient to wear the proper glass that will correct the existing error of refraction, and you will have relieved him of his symptoms of spasm and of asthenopia.

In some cases you may find that there is a tendency to a return of the spasm when the eyes are used, even with the proper correcting glasses; if so, you must again order the atropine (2 grs. to the ounce) to be used, perhaps for one or two months, until the accommodation remains at rest when rays from the punctum remotum enter the eye.

SIXTH LECTURE.

OPHTHALMOSCOPY.

Amaurosis and Amblyopia—History and description—Conjugate foci—Loring's ophthalmoscope—Valk's improvement—Emergent rays—Emmetropia—Rule for examination—Hypermetropia—Rule for examination—Myopia—Rule for examination—Astigmatism—Diagnosis of—Rules for the examination—The different varieties of—Influence of the accommodation—The examiner may be ametropic—The indirect method.

Gentlemen:—One of the most important aids to the proper study of the errors of refraction is the use of the ophthalmoscope. It will not only reveal to us the various pathological conditions that may exist in any part of the dioptric media or at the fundus, but it will also give us a key to the exact condition of refraction, and enable us to estimate the total error in the several varieties as described.

Before the days of ophthalmoscopy the diseases of the interior of the eye were totally unknown, and all deficiency in the sight, no matter what the cause or pathological condition, received the name of *amblyopia* or *amaurosis*,—words that were used without any practical meaning whatever. They denote that the vision is impaired and below the normal standard. But they give us no clue to any pathological condition that may exist in the eye, or to any error of refraction that may reduce the vision below the standard.

Amaurosis, according to the Greek definition, simply means " to render obscure," and is now very seldom used; the term *amblyopia* is still used, in connection with that

condition of reduced vision for which no cause can be assigned by the most careful examination with the ophthalmoscope. You will frequently meet with cases, particularly in high degrees of hypermetropia, where, even with the correcting glass, you cannot bring the visual acuteness up to the normal standard of $\frac{20}{20}$, and yet, under an examination with the ophthalmoscope, you will find the refractive media and the retina apparently in a perfectly normal condition. LANDOLT, of Paris, ascribes this condition to a non-development of the retinal elements, a congenital amblyopia, as the hypermetropic eye is one that is not fully developed—the length of the optic axis will show the diminished size. This is a very admirable theory, and one I am inclined to adopt. Others think that this amblyopia, as found in the hypermetropic eye, is due to the reason that the perceptive elements of the retina are not sufficiently stimulated and the visual impressions are suppressed, particularly so in relative hypermetropia. But I think you will have one case that points to one theory, and another that will point the other way.

The importance of a perfect understanding of the use of the ophthalmoscope in all cases of refraction should be fully appreciated. To gain that end, you should be familiar with the principle upon which it is based; and when you have perfected yourselves in its use in diagnosing and estimating the errors of refraction, you will then realize how efficient it is in the diagnosis of all diseases of the dioptric media and retina. The estimation of the refraction should be attended to before we can give a positive opinion of the condition of the fundus.

It is not my purpose to give you an extended account of the history of the ophthalmoscope—for this I would refer you to LANDOLT'S and DE WECKER'S works—nor of the many diseases of the fundus that are revealed by its use; but I would fain make these lectures of practical help by

a description of the instrument in its perfect form, as now in use.

Invented by HELMHOLTZ, in 1851, it consisted simply of a mirror, with an opening in the centre, to which the eye of the observer may be applied in the path of the return rays, as they pass outward from the eye, after the fundus is illuminated by the reflected rays from the mirror.

When we look at an eye the pupil appears perfectly black—you cannot see beyond the iris; and yet we know that the lens and vitreous beyond are perfectly transparent. You cannot see the entrance of the optic nerve, the blood-vessels proceeding from it, nor the beautiful tapetum of the retina. How shall we account for this? Simply because we cannot place the eye in the track of the return rays. We have all noticed that the eye of a cat shines brightly if you approach it in the dark; particularly if you so hold a light that your own eyes are shaded. This is because the cat's pupil is largely dilated; and, as the light is reflected from the retina, the pupil appears red, the natural color of an illuminated retina. So it is with the human eye, observed through the aperture of the ophthalmoscope.

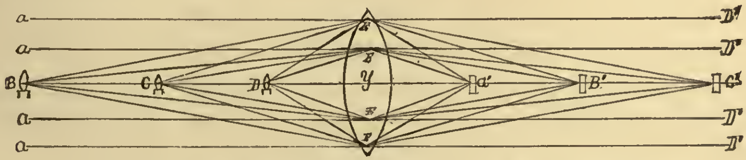


FIG. 31.—CONJUGATE FOCAL POINTS OF A BI-CONVEX LENS.

It is a well-known fact that rays passing through a lens, as described in Lecture II., will take the same course, no matter which way they pass. If you pass the rays from a candle placed in front of a double-convex lens, they will be refracted and will focus upon a screen beyond the lens; now change them, and place the candle where the screen was, and you again find the rays will focus at the point where the candle stood: this is according to the laws of the conjugate foci.

By referring to the above diagram, fig. 31, you will see the direction in which rays of light pass through a convex lens *Y*. According to the laws of conjugate foci the angle of refraction is always the same, no matter at what point you place the source of illumination. If we have parallel rays, as *a*, *a*, *a*, *a*, they will focus on the screen at *a′*; then, if we bring the illumination nearer, as at *B*, you will find the focal point changed to the screen at *B′*, and so on. As you bring the illumination nearer, the focal point recedes until you come to the point *D*, when the rays, after passing through the lens, will now have a direction parallel to the points at *D′*, *D′*, *D′*, *D′*. In each position, the angle formed by the refraction, *aEa′*, or *BEB′*, is the same. We may substitute the position of the screen for that of the illumination, and the rays of light will pass the other way, with the same refractive angle.

It is this law of conjugate foci that forms the image upon the retina, and as the rays are reflected by the retina they will return to the source of illumination, provided the examined eye be emmetropic. Consequently, if we would see the fundus of the eye, we must place our own eye so that the return rays can enter and focus upon the retina.

It is by the use of the ophthalmoscope, then, that we can place the eye in a position to intercept those return rays as they pass outward. Now the pupil of the examined eye appears of a beautiful orange-red color, while any opacities that may obstruct the return rays at any point will appear to us a black spot in the pupillary space, whether situated in the cornea, the capsules, the lens, or in the vitreous.

The best ophthalmoscopes now in use consist of a simple mirror, having a perforation in the centre, slightly concave on its surface, so that it will concentrate the rays of light, and make the illumination much more brilliant:

while, placed behind the mirror, we have a disc, containing a series of convex and concave lenses, which can be so rotated as to bring the various lenses before the aperture in the centre. By this means we cause the rays of light as they are reflected from the retina of the eye under examination to pass in a perfectly parallel direction; and, if the observer's eye be adapted to these rays, the glass placed at the aperture will give the existing error of refraction in the subject's eye.

FIG. 32.—VALK'S IMPROVEMENT ON LORING'S OPHTHALMOSCOPE.

Loring's ophthalmoscope, with the quadrant behind the disc of glasses, containing concave and convex .05 and 16. D, is undoubtedly the best refraction instrument. To this I have added a rack and wheel motion, so that the disc can be rotated without removing the ophthalmoscope from the examiner's eye when estimating refraction. I trust you will find this attachment serviceable. A full account of it, published in the *Medical Record*, vol. xxxi., No. 17, page 478, is as follows:

"In the use of this ophthalmoscope for several years past, it has seemed to me that if some mechanism could be devised whereby the various lenses might be readily brought behind the aperture without removing the instrument from the eye, the accommodation would more

readily tend to relax in the estimation of hypermetropia, and that this would be a decided advantage. With this end in view I have devised this improvement to Dr. E. G. Loring's instrument, as shown in the cut."

This consists of a rectangular bar, connecting the ophthalmoscope with the handle, somewhat longer than the bar now in use. Upon this bar is a slide, with the edges roughened so that it can be held steadily and firmly with the thumb and forefinger, and is made to pass freely up and down. Passing upward from the slide is a flat rack of brass, having on one side a series of small teeth, which act upon a cog-wheel attached to the disc containing the lenses. This cog-wheel motion is so set that when the slide is in the middle of the bar the aperture in the disc will be over the aperture in the ophthalmoscope.

It will be readily seen, then, that in the use of this ophthalmoscope, by simply pulling the slide downward will cause the disc to rotate to the right, thus bringing the convex glasses successively behind the aperture; or, pushing the slide upward, the concave glasses are similarly placed.

The small quadrant that contains the convex and concave glasses of 16. D and .05 D is fastened to the segmented cover of the back of the ophthalmoscope by the two small screws in the centre, and when it is to be used, to obtain the stronger glasses, it is simply necessary, if convex glasses are needed, to put the convex 16. D over the aperture, then push the slide up to the top of the bar, and as it is pulled downward the convex combinations will be successively placed behind the aperture, from + 8. D to + 23. D. The same action of the slide with the — 16. D, behind the aperture will make all the combinations between — 9. D to — 24. D, only pull the slide down to the lowest point first, and then push it up as the stronger glasses are needed. The .05 D can be added to any glass in the disc, as wanted.

I am inclined to think that by the use of this attachment to Loring's ophthalmoscope our examination of the fundus and the estimation of the errors of refraction will be much more exact and satisfactory, as the ease with which we can bring the successive glasses before the eye will allow the examiner's accommodation to become easily relaxed in the estimation of hypermetropia, and also to more readily select the weakest glass in the estimation of myopia.

Since I have used the above improvement on the ophthalmoscope I learn that the same motion was used on a single disc several years ago, and reported in Graefe and Saemish's "Hand-Book of Ophthalmology," vol. iii., part i., page 135, but was unknown to me until after I had perfected and used this improvement.

To understand fully the use of the ophthalmoscope in estimating the refraction of an examined eye, we must study closely the direction of the emergent rays. Having rendered the fundus of an eye luminous by the mirror of the ophthalmoscope, it does not matter whether the rays from the mirror come to a focus or not, so long as they will illuminate the retina sufficiently. As the retina sends outward rays of light, we have a luminous point within the eye. From this point, as the rays pass through the dioptric media, they will be bent according to the index of refraction and the curvature of the refracting surfaces which they meet in their passage outward.

Now we have shown that the rays of light when passing through a lens are refracted and will always pass backward in the same way; and that when coming from a luminous point, either nearer to or farther from the nodal point of a convex lens, they will have the same angle, so that if the luminous point be brought nearer the lens the rays will pass beyond it in a divergent direction, and if the luminous point be removed beyond the focal distance

the rays will then pass beyond the lens in a convergent direction.

You will find this fact of great assistance in estimating refraction, as the same law takes place in the eye. In the emmetropic eye you have seen that its dioptric apparatus is adapted for parallel rays, consequently when these rays pass in the emmetropic eye they will exactly focus upon the retina and, being reflected, will return in the same paths, passing outward in the same direction. Hence we see that the emmetropic eye is not only adapted for parallel rays, but also that the emergent rays are parallel. If a convex glass be placed at the aperture of the ophthalmoscope it will render the rays convergent, so that the retina cannot be seen; while, if we place a concave lens behind the aperture, it will render the rays divergent, and the retina can still be seen by the action of the accommodation.

We would, then, adopt this rule for the diagnosis of emmetropia with the ophthalmoscope, provided the observer's eye be emmetropic and the accommodation at rest, as follows: The emmetropic eye is one that sends outward, when illuminated, parallel rays, whose fundus can be distinctly seen through the aperture, but the image of which will be blurred by all convex glasses.

Let us now examine the hypermetropic eye, or one in which the optic axis is too short, but whose refractive index is the same as that of the emmetropic eye.

When we illuminate the hypermetropic eye with the ophthalmoscope we have the return rays from the fundus passing from a point nearer the refracting surfaces than the focal distance (see fig. 28, page 58), consequently, having the same refractive angle, the rays pass out divergently, and the fundus can be distinctly seen through the aperture by slight exercise of the accommodation. Now place a weak convex lens behind the aperture and the

fundus can still be distinctly seen, and the strongest convex lens by which the details of the fundus are clear and distinct will represent the total amount of hypermetropia in the observed eye.

This fact is very simple. Because, if the emergent rays are divergent, to bring them to a focus in the emmetropic eye, with the accommodation at rest, you must render them parallel ; wherefore you place a convex lens before your eye to bend these divergent rays until they become parallel.

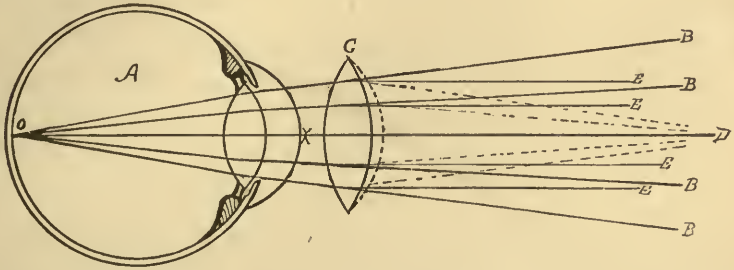


FIG. 33.—ACTION OF A CONVEX LENS ON THE EMERGENT RAYS OF HYPERMETROPIA.

I would illustrate this by the preceding diagram, in which *A* represents the eyeball with a shortened optic axis, *OX*, and the emergent rays *B*, *B*, *B*, *B*, pass outward divergent ; but when passing through *C*, a convex lens, they are bent toward the focal point, yet only sufficiently to render them parallel, as shown by the lines *E*, *E*, *E*, *E*.

For hypermetropia our rule would be as follows : That the hypermetropic eye is one which sends outward, when illuminated, divergent rays, whose fundus can be distinctly seen through the aperture by an effort of the accommodation, and that the strongest convex glass by which the details of the fundus are clear and distinct will represent the amount of total hypermetropia. You will notice that in hyperopia we take the strongest glass, as you cannot use one too strong or over-correct the hypermetropia,

because, when you do, the image of the retina in the observed eye will be blurred.

Then you must remember, as you estimate the refraction with an ophthalmoscope, that you can always see the details of the fundus clearly in hyperopia, and with your own accommodation relaxed, the strongest glass which will render the emergent rays parallel must represent the amount of total hyperopia ; while too strong a convex glass will make the emergent rays convergent, and they cannot be seen with the emmetropic eye. See the dotted lines in fig. 33 ; the increase in the power of the convex lens being also shown by dotted lines.

In the myopic eye, you have one in which the optic axis is too long, though the refractive index is the same as in the emmetropic eye. Now, when you illuminate this fundus, you have the return rays coming from a point beyond the focal distance of the refractive surfaces, and, following the same laws, they will pass outward in a convergent direction, and cannot be seen by an emmetrope. Place a convex lens behind the aperture, and we will render the rays more convergent and the fundus more blurred ; but if we use a concave lens we will cause the emergent rays to pass outward in a direction parallel to one another. Then the weakest concave lens that will render the rays parallel will show the amount of existing myopia in the observed eye. You must remember to use the weakest concave lens, because if you use a stronger glass, you will simply render the rays of light divergent ; these will then be focused upon your retina by your accommodation, and the amount of myopia will be over-corrected.

Our rule would then be, for the diagnosis of simple myopia with the ophthalmoscope as follows : The myopic eye is one that sends outward, or reflects, when illuminated, convergent rays, whose fundus cannot be distinctly

seen through the aperture of the ophthalmoscope with the emmetropic eye ; and the weakest concave glass by which the details of the fundus can be distinctly seen, or will render the emergent rays parallel, will represent the total amount of myopia.

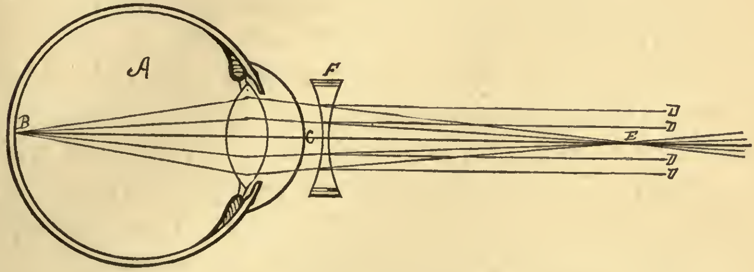


FIG. 34.—THE MYOPIC EYE, ITS EMERGENT RAYS, AND THEIR CORRECTION WITH THE GLASS *F*.

Let me illustrate this diagnosis by the above diagram, in which *A* represents the myopic eye, with the optic axis *BC* longer than normal. When we illuminate this eye, the emergent rays coming outward are rendered convergent, as they come from a point beyond the focal distance of the refractive apparatus, and will come to a focus at the point *E*; but when passing through a concave lens, as at *F*, they are refracted outward and become parallel, *D*, *D*, *D*, *D*, and the weakest glass that will produce this effect will represent the total degree of myopia.

The diagnosis of the different varieties of astigmatism with the ophthalmoscope are somewhat more difficult, although upon the same principles which govern simple hypermetropia and myopia. But now we study the emergent rays in the two principal meridians or planes of the eye ; always estimating the meridian nearest to the emmetropic plane first, and remembering that these planes are always at right angles to each other, though they may be at any degree of the arc of a circle.

Should the observed eye be a case of simple hyperme-

tropic astigmatism, in which the vertical plane is emmetropic and the horizontal plane hypermetropic, you will observe on examination with the ophthalmoscope that all the details of the fundus are distinctly seen through the aperture, particularly all the fine vessels of the optic disc. You will remember that these fine vessels of the disc will always give you excellent points for your diagnosis of astigmatism. Now, if we place a convex glass behind the aperture, you will notice that the horizontal vessels become blurred, and that the strongest convex glass with which the vertical vessels can be clearly seen will represent the amount of hypermetropic astigmatism. The correcting glass will be a simple convex cylindric glass with the axis vertical. The direction of the finer vessels that can be seen with the correcting glass will show the direction of the emmetropic meridian, which in this case would be vertical, or at 90° of the arc of a circle.

If we would illustrate this with our diagrams, let *A* show a section through the vertical plane, and *B* a section through the horizontal plane.

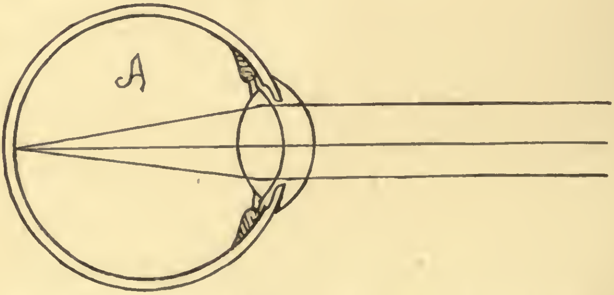


FIG. 35.—THE EMMETROPIC PLANE; ENTERING RAYS, Ah.

In the diagram *A* you will notice that the rays passing inward will focus upon the retina; while in the diagram *B* they will strike the retina before they have come to a focal point. Then with these rays illuminating the fundus, and we study the course of the emergent reflected rays,

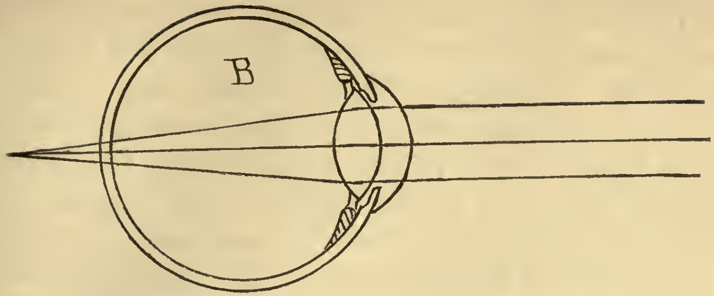


FIG. 36.—THE HYPERMETROPIC PLANE; ENTERING RAYS, Ah.

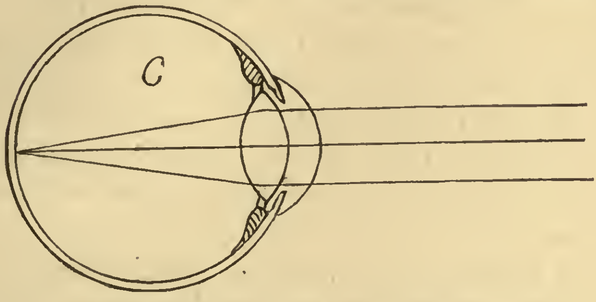


FIG. 37.—THE EMMETROPIC PLANE; EMERGENT RAYS, Ah.

we find that those passing outward in the vertical or emmetropic plane, as in *C*, follow the same paths and emerge parallel, while those passing outward

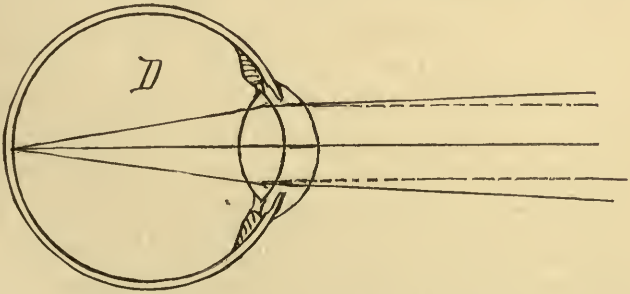


FIG. 38.—THE HYPERMETROPIC PLANE; EMERGENT RAYS, Ah.

in the horizontal plane, as shown in this diagram *D*, through a portion of the cornea, with a lesser degree of curvature, are not sufficiently refracted, and so emerge divergent. Such being the case, you will readily see

that the vertical plane would be over-corrected by a convex glass, while the horizontal plane will be made emmetropic. Consequently, to correct this error of refraction, we must use a glass which will only refract rays of light in the horizontal plane; and, as the cylindric glass will only refract rays at right angles to its axis, we must place the axis of the glass vertical, or at 90°.

Our rule for the diagnosis of simple hypermetropic astigmatism with the ophthalmoscope would then be: That the hyperopic astigmatic eye sends outward reflected rays in two principal meridians or planes at right angles to each other, one being emmetropic, the other hypermetropic; that the emergent rays of the emmetropic plane are parallel, while those of the hypermetropic plane are divergent; that the strongest convex glass with which we can see the vessels, in any one meridian, will represent the amount of existing hypermetropic astigmatism, and that the axis of the cylindric glass should be *parallel* with the direction of those vessels that are seen through the correcting glass. For a more complete explanation of this I would refer you to the lecture on astigmatism.

If we now take the example of an eye in which we have the condition of compound hypermetropic astigmatism, we must calculate the refraction of the two principal meridians, in which we find that the amount of hypermetropia is greater in one meridian than in the other. Then, for example, let us take the vertical and horizontal meridians as the principal ones, and we shall find that in the vertical meridian the rays passing in parallel focus at a point behind the retina, and the rays passing in the horizontal meridian also focus in the same direction but at a point nearer the cornea than do those in the vertical plane; consequently, the emergent rays in the vertical plane will be divergent, and those in the horizontal plane will also be divergent, but more positively than those in

the vertical. It will therefore take a stronger glass to render the rays in the horizontal plane parallel than it will in the vertical ; and we require a correcting convex glass that will refract rays of light in all meridians, but more in one meridian than in the other.

We will make our diagnosis of compound hypermetropic astigmatism with the ophthalmoscope in this way : On examination, the fine vessels of the fundus will be clearly seen in all directions unless a very high degree of hypermetropia exist, and the strongest convex glass that will render any of the finer vessels of the disc indistinct will represent the amount of hypermetropia ; while the strongest convex glass with which the vessels in the opposite meridian can be clearly seen will represent the amount of hypermetropia and astigmatism. The direction of these vessels will show the axis of the correcting cylindric glass. If we find that the horizontal vessels are rendered indistinct with a convex glass of $\frac{1}{20}$, or 20 inches focal distance, and that the vertical vessels can be seen with a convex glass of $\frac{1}{10}$, or 10 inches focal distance, we have compound hypermetropic astigmatism that would be corrected by a spherical glass of $+\frac{1}{20}$, combined with a cylindric glass of $+\frac{1}{20}$, axis 90°, or vertical.

Our rule for the diagnosis of compound hypermetropic astigmatism then becomes as follows : That the compound hypermetropic astigmatic eye is one that sends outward divergent rays in all meridians, but which are more divergent in one meridian, or plane, than in the other ; that these two principal planes are at right angles to each other ; that the convex lens which renders the vessels in one meridian indistinct will represent the amount of hypermetropia, that the strongest convex glass with which we can see the vessels in the meridian at right angles, less the amount of hypermetropia, will represent the amount of hypermetropic astigmatism ; and that the axis of the

correcting convex cylindric glass must be *parallel* with those vessels that can be seen with the *strongest* glass.

As in the hypermetropic eye we have less refracting power in one meridian than in the other; so we may also have in the myopic eye a greater refracting power in the different meridians, each of these conditions of astigmatism generally existing in the curvature of the corneal surfaces.

The most simple form of this error of refraction is that of simple myopic astigmatism, in which we have the refraction of one meridian emmetropic, and that of the other, at right angles to it, myopic. In this case, let us see in what direction the rays of light pass inward and outward. We again divide the eye into two principal planes, at right angles to each other. Now as the rays pass inward in the vertical plane, we find they will focus exactly upon the retina, as in the diagram *A*; while in the

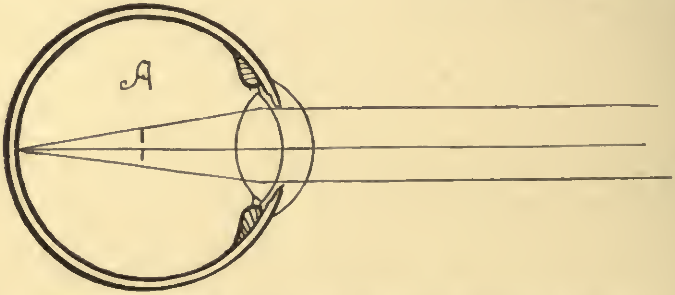


FIG. 39.—THE EMMETROPIC PLANE; ENTERING RAYS, Am.

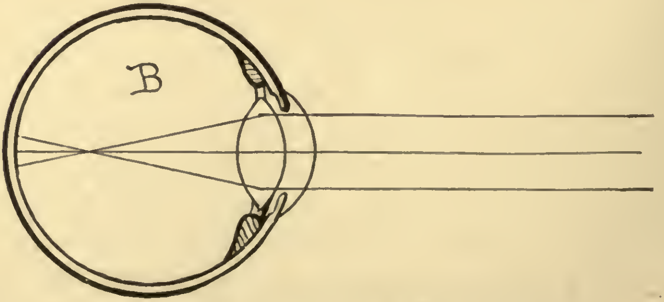


FIG. 40.—THE MYOPIC PLANE; ENTERING RAYS, Am.

horizontal plane we find that, as the curvature of the cornea is greater than in the vertical, all the rays will be refracted with greater power, and must focus in front of the retina as shown in the diagram *B*.

As these rays of light are reflected from the retina, we will find that the rays composing the vertical plane pass outward in the same direction as they entered, and are parallel after leaving the eye, as shown in this diagram *C*;

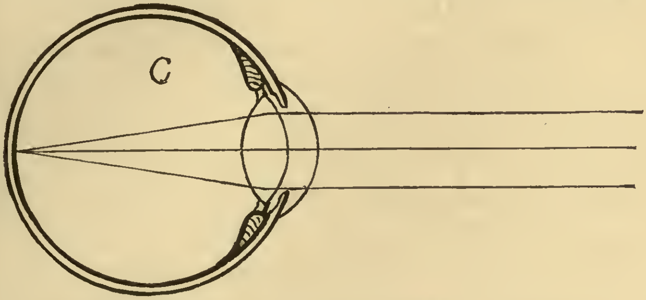


FIG. 41.—THE EMMETROPIC PLANE; EMERGING RAYS, Am.

while the rays that pass outward in the horizontal plane are refracted by the increased curvature of the cornea in that meridian, and consequently focus in front of the eye. This is shown in the diagram *D*.

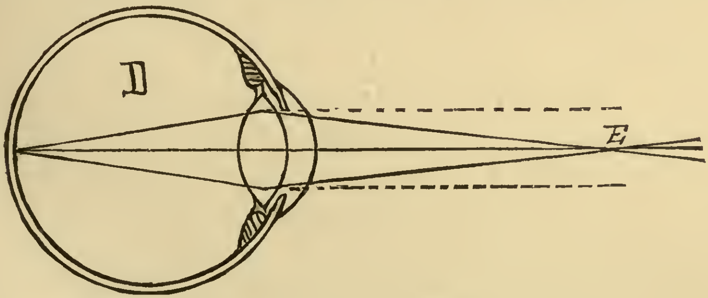


FIG. 42.—THE MYOPIC PLANE; EMERGING RAYS, Am.

These emerging rays cross at a focal point *E*, and now diverge. To diagnose this condition with the ophthalmoscope, we must again study each meridian separately, and so decide the refraction of each.

When you examine the fundus of an eye that has simple myopic astigmatism, you will notice that the finer vessels of the disc which pass in certain directions are indistinct or blurred, according to the degree of myopia; while all those vessels running in a direction at right angles are clear and distinct. Now if you place a convex glass behind the ophthalmoscope they will all be blurred, but if you use a concave glass you will find that all the vessels become clear in each meridian. The weakest glass that will render the blurred vessels clear will give you the amount of myopic astigmatism, and the axis of the correcting cylindric glass must be placed at *right angles* to the vessels that appeared distinct at first.

I would illustrate this to you by an example of an eye, in which you will notice that through the aperture the horizontal vessels are clear and well defined, while the vertical vessels are indistinct or blurred. Now if we place a concave glass of $\frac{1}{20}$ behind the aperture, this being the weakest glass for our diagnosis, we find that all the vessels are perfectly distinct. Then, if the axis of the cylindric glass should be at *right angles* to the vessels first observed, we have as the correcting glass a simple concave cylindric glass of $\frac{1}{20}$, with the axis placed at 90°, or vertical.

My rule for the diagnosis and estimation of simple myopic astigmatism with the ophthalmoscope would then be as follows: That the myopic astigmatic eye sends outward reflected rays of light in two principal meridians at right angles to each other, one being emmetropic, the other myopic; that the emergent rays of the emmetropic plane are parallel, while those of the myopic meridian are convergent; that the weakest concave glass with which we can see the vessels in the blurred meridian will represent the amount of myopic astigmatism; and that the axis of the cylindric glass should be placed at *right angles* to the

direction of the vessels which are clearly seen without a glass.

These same principles hold good in the case of compound myopic astigmatism ; but we now have a condition of the elongation of the optic axis, with a greater power of refraction in one meridian of the cornea than in the other. Hence, if we measure the refraction of the two principal meridians of the eye, we will find that in one meridian there is a certain amount of myopia, and in the other a still greater degree, with the axis of the cylindric glass at *right angles* to the vessels seen by the *weakest* concave glass.

In what direction will the rays of light pass through the dioptric media, in the two principal planes of an eye that has compound myopic astigmatism ? In the vertical plane we still find that parallel rays will focus in front of the retina, and also in the horizontal plane. But in one plane the focal point will be much nearer the retina than in the other, consequently, as the emergent rays in each plane must pass through the same refractive apparatus, but coming from a point beyond the focal distance of the refractive surfaces, these rays will pass outward in a convergent direction. Thus they have a focal point for each meridian, situated on the visual line, one being nearer to the eye than the other, according to the refractive power of each plane. It is an interesting fact that these emergent rays have two focal points and an interval, the same as the "interval of Sturm," formed by a convex spherical and cylindric lens.

You will also observe that, on the examination of the fundus with the ophthalmoscope, all details are blurred, and if you place a weak concave glass behind the aperture you will first notice that certain vessels in one plane become clear, and that those at right angles to them are still indistinct. This glass will then represent the

amount of myopia produced by the elongation of the optic axis, and should consequently be spherical. Again, place a stronger concave glass behind the aperture until all the vessels of the fundus come out clear, and the difference between these two glasses will give you the amount of astigmatism, with the axis of the cylindric glass placed at right angles to the direction of the vessels first seen distinctly.

Let us illustrate this in a case where the fundus is completely blurred in all directions. If we now place a concave glass of $\frac{1}{20}$ behind the aperture, we shall see clearly all the vessels that pass horizontally, but not the vertical vessels; then place a still stronger concave glass behind the aperture, as $\frac{1}{10}$, and the vessels running vertically are now as clear as the others. If we calculate the axis of the cylindric glass as at right angles to the vessels first seen clearly, and subtract the weaker glass from the stronger, we would have, as the correcting glass for this compound myopic astigmatic eye, a concave spherical glass of $\frac{1}{20}$, combined with a concave cylindrical glass of $\frac{1}{20}$, with the axis at 90°, or vertical.

Reasoning from these facts we therefore conclude that our rule for the diagnosis of compound myopic astigmatism should be as follows: That the compound myopic astigmatic eye is one which sends outward reflected rays, convergent in all meridians, but more convergent in one meridian than in the other; that the two principal planes are at right angles to each other; that the weakest concave glass which will make the vessel clear in one meridian will show the amount of general myopia, while the weakest concave glass that will render all the finer vessels clear will represent the amount of astigmatism with the axial myopia; and that the axis of the cylindric glass should be placed at right angles to the direction of the vessels seen with the weakest concave glass. You will note that

the vessels in myopia are seen in the meridian of greatest ametropia, but that in hypermetropia it is just opposite, wherefore the axis of the cylindric glass must be changed.

We now come to the diagnosis of the last variety of regular astigmatism with the ophthalmoscope, where we have two distinct meridians, at right angles to each other, and exactly opposite in their refraction.

This variety is called *mixed* astigmatism, because we have a combination of the two previous forms: one meridian will be hypermetropic, while that at right angles to it will be myopic. The simplest method to study this condition of refraction will be on the supposition that the retina is placed at the same distance from the cornea as in the emmetropic eye, but that the curvature of the cornea is much greater than normal in one meridian, and much less than normal in the opposite meridian.

You will readily understand that, as the rays of light from a distant point, passing inward parallel, will in one meridian strike the retina before they have been brought to a focal point, in the meridian at right angles to it the rays will focus in front of the retina. Consequently all vision for distance will be blurred.

This can be illustrated by the diagrams, in which the meridian of lesser curvature is shown at *A*, fig. 43, where

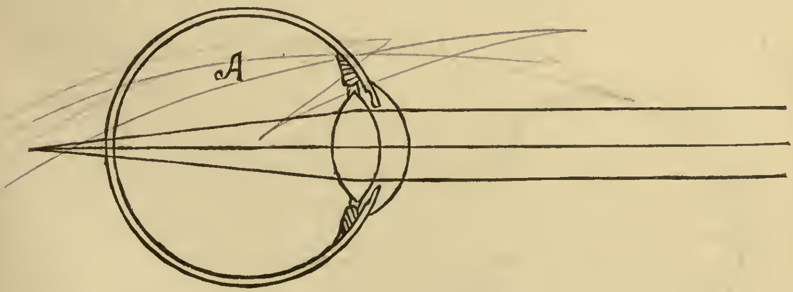


Fig. 43.—The Hypermetropic Plane; Entering Rays, Ahm.

you will notice that the parallel rays focus at a point behind the retina, while in fig. 44, at *B*, you will see that

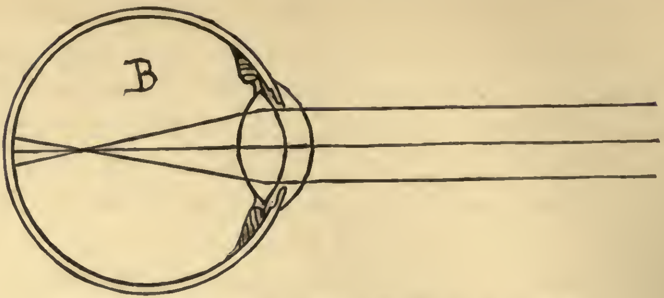


FIG. 44.—THE MYOPIC PLANE; ENTERING RAYS, Ahm.

they cross, and strike the retina in a divergent direction. Now as these rays of light are reflected by the retina they will pass outward in each meridian with the same refractive angle, but as those which pass outward in the hypermetropic meridian will take the direction as shown at *C*, fig.

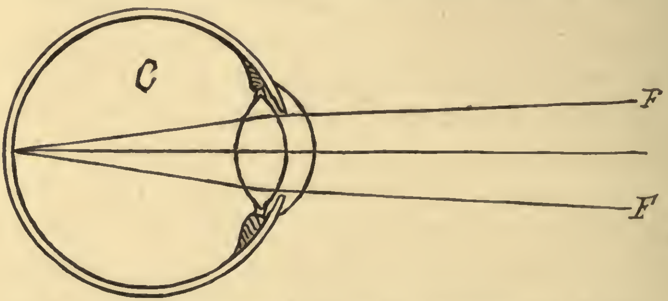


FIG. 45.—THE HYPERMETROPIC PLANE; EMERGING RAYS, Ahm.

45, as they come from a point inside the focal distance of the refracting surfaces, consequently they must pass out

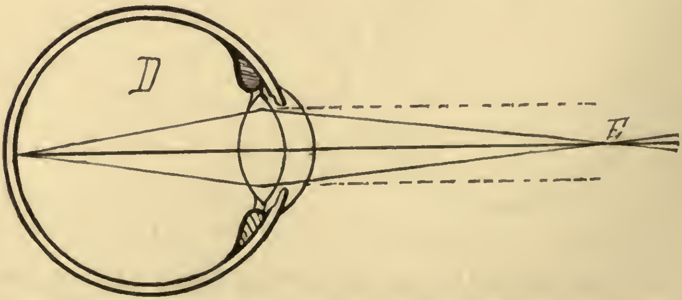


FIG. 46.—THE HYOPIC PLANE; EMERGING RAYS, Ahm.

in a divergent direction to *F*, *F*. But the rays of light in the other meridian, as at *D*, fig. 46, as they are reflected by the retina, pass out from a point beyond the focal distance of the refracting surfaces, and, having a convergent direction, will come to a focal point at *E*, at a distance from the eye equal to the amount of myopia in that plane.

The diagnosis of this condition of refraction with the ophthalmoscope is not one of much difficulty, as we simply estimate the refraction of each meridian separately. The appearance of the vessels at the fundus will at once impress upon us that the eye is astigmatic, and that it must be hypermetropic in one meridian and myopic in the other, as you will at once observe that all the vessels in one meridian are clear and well defined, while all those at right angles to them are very indistinct.

I wish to impress upon you that this condition and appearance of the fundus in a case of mixed astigmatism must be distinctly understood. All these statements are made in the belief, on my part, that nearly all oculists, in the use of the ophthalmoscope for the diagnosis and estimation of refraction, cannot control their own accommodation so that their ciliary muscles shall be perfectly at rest. Hence, when I make the statement that the vessels in one meridian are clearly seen through the aperture, it is because the rays passing out in the meridian at right angles to that, and *which define the edges of the vessels*, are divergent, and by the unconscious action of our accommodation we exactly focus those rays upon the retina, thus forming the edges of the vessels. Now the rays passing outward in the other meridian, of greater curvature, are convergent, and will focus before they reach our retina; but, when they do impinge, they *overlap* each other, and so assist to form the image of the vessels or lines that pass in that meridian.

If our accommodation were completely relaxed, or were

paralyzed by the action of some mydriatic, as atropine, then the vessels in all directions would become blurred, because we could not focus the divergent rays; but, the accommodation being active, the most natural function of the human eye is to cause all divergent rays of light to exactly focus upon the retina, while in the case of convergent rays, which is an anomaly of nature, we must use some means to cause them to pass in such a direction that they may focus upon the retina of the observer's eye.

How, then, shall we make the diagnosis and estimate the refraction in a case of mixed astigmatism? As we have stated, there is hypermetropia in one meridian, and myopia in the other; so we can focus the rays of light in the hypermetropic meridian by the act of the accommodation, and consequently the edges of the vessels passing in the myopic meridian will be seen clearly and all other vessels will appear blurred.

In the examination of the eye with the ophthalmoscope you will see the fine vessels passing in the same direction—say that of the vertical meridian. You may have this appearance of the fundus in simple myopic astigmatism; but, if you place a convex glass at the aperture, and the vessels are still clearly seen, you must have mixed astigmatism. Then the strongest convex glass with which these vessels can be seen will give you the amount of hypermetropia in one meridian, and we place the axis of the cylindric glass parallel with the direction of these vessels.

Then find the weakest concave glass with which you can see the vessels passing in the opposite meridian at right angles to the first, and this will give you the amount of myopic astigmatism, with the axis of the concave cylindric glass at right angles to the convex glass. You will readily see by this that, if the vertical vessels are seen through the aperture, and also with a convex glass of

1 D while the horizontal vessels are only seen with a concave glass of 1 D, we have a case of mixed astigmatism, equal to + 1 D, cyl. axis 90°, — 1 D, cyl. axis 180°.

Our rule then is as follows : In a case of mixed astigmatism the emergent rays have a divergent direction in one meridian, and are convergent in the meridian at right angles to the first ; then the strongest convex glass that will render the divergent rays parallel will give the amount of hypermetropia, and the weakest concave glass the amount of myopia, with the axis of the convex cylindric glass parallel to the vessels seen through the aperture, and the axis of the concave cylindric glass at right angles to the same vessels.

I will refer you to the Lecture on Astigmatism for a more full explanation of the theory of the action of the rays of light in the diagnosis of astigmatism with the ophthalmoscope, and in which I have explained the reasons why the axis of the correcting cylindric glass should be placed parallel to the vessels in hypermetropia, and at right angles to the vessels in myopia.

From the foregoing rules, I do not think it necessary or advisable, to use any cylindric glasses on the ophthalmoscope, as the diagnosis can be readily and easily made with the spherical glasses in the disc attached to all good ophthalmoscopes.

There is also another point which you must take into consideration in the estimation of the degrees of refraction with the ophthalmoscope—that is, the actual refraction of the examiner's eye should he be ametropic. This must be allowed for in your estimation of the total error of refraction, or you must place a suitable correcting glass at the aperture which will adapt the examiner's eye for parallel rays. This is particularly necessary, if the examiner should happen to be astigmatic. He should have a suitable glass that will correct the astigmatic curvature,

placed in a clip at the aperture, so as to make his eye practically emmetropic.

Should the examiner be simply hyperopic or myopic, then he can add or subtract the amount of his own refraction to the glass required to correct the total error of refraction by the ophthalmoscope. Thus, if the examiner has a hyperopia of 1 D, he can easily see the fundus of a myopic eye of 1 D. As the emergent rays of the examined eye will be convergent, coming to a focus in front of the eye, while the examiner's eye, being hyperopic, is adapted for rays that will focus 1 D behind his eye ; consequently the emergent rays from the myopic eye will exactly focus upon the retina of the examiner's eye.

Then if the examined eye should be myopic, of 2 D, and the examiner's eye 1 D hypermetropic, he will see the fundus of the examined eye with a concave glass of 1 D, as his own refraction will neutralize 1 D of the examined eye ; and so, to get the total amount of myopia, he must add to the glass used in the ophthalmoscope the amount of his hyperopia, and we have a total myopia of 2 D.

It is just the same if the examiner be myopic, as he must use a concave glass to correct his myopia ; but he must subtract the amount of his myopia from the glass required to see the details of the fundus when he examines a myopic eye, or he must add the amount if the examined eye be hypermetropic. Because if the examiner be myopic 1 D, and can see the fundus of a hyperopic eye with a convex glass of 1 D, he will have a total hyperopia of 2 D ; while, should he require a concave glass of 3 D, he will have a myopia of only 2 D.

You will see by these diagrams the direction of the rays of light, when passing from one eye to the other, when the error of refraction of one eye is hyperopic and that of the other myopic, while in the lower diagrams

the direction of the rays, after correction, is shown by the dotted lines.

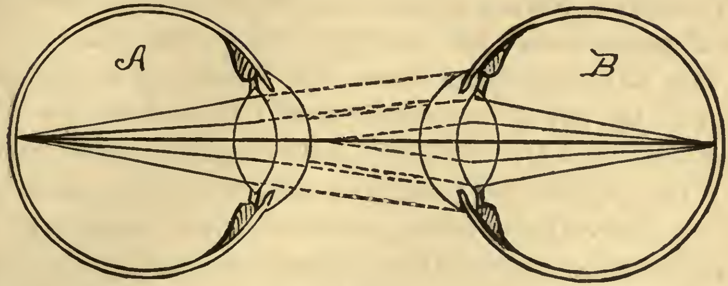


FIG. 47.—RAYS PASSING FROM THE MYOPIC TO THE HYPERMETROPIC EYE ARE PARALLEL IN THE SAME DEGREE OF REFRACTION.

In this diagram, if *A* is the eye of the examiner, and *B* the examined eye, one being hypermetropic and the other myopic, you will see by the dotted lines, which represent the emergent rays from the retina of each eye, that as they have emerged they become parallel to each other, and consequently the rays proceeding from one retina will focus upon the retina of the other eye ; the refractive error of each eye being of the same degree, but with one eye myopic and the other hypermetropic.

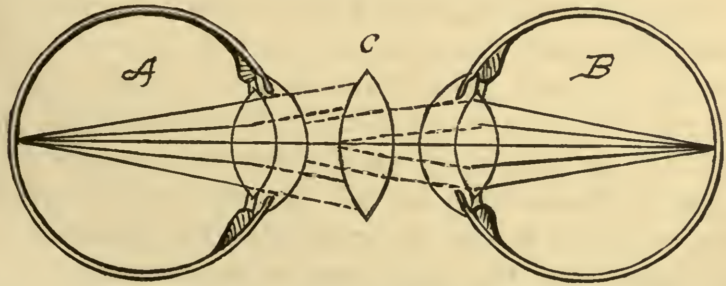


FIG. 48.—THE CONVEX GLASS C CORRECTS THE MYOPIA WHEN EXAMINED BY THE HYPERMETROPE OF SLIGHT DEGREES.

Now in this diagram we have the same condition of refraction, but the examiner's eye, *A*, has a greater degree of hypermetropia than the examined eye, *B*, has of myopia ; consequently the rays from the examined eye, *B*, will not

be sufficiently convergent to focus upon the retina of the examiner's eye when the accommodation is at rest, but will require a convex glass, *C*, to make the rays from the eye *B* parallel with the emergent rays from the eye *A*, so that they will focus upon the retina. To illustrate this: If the eye *B* has a myopia of 1 D, and the eye *A* a hyperopia of 2 D, then it will only require a convex glass of 1 D to render the emergent rays from the examined eye parallel with the emergent rays of the examiner, these being the rays to which the hyperopic eye is adapted. The same lens would be required if *B* was the examiner's eye.

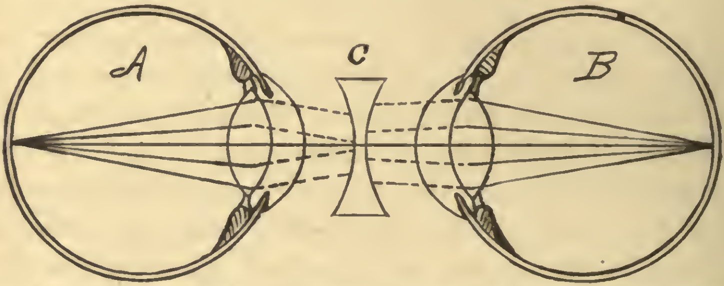


FIG. 49.—THE CONCAVE GLASS C CORRECTS THE MYOPIA OF LOW DEGREES WHEN EXAMINED BY A MYOPE.

Again, in this diagram we have the emergent rays from both eyes, *A*, *B*, convergent, but more so in one than in the other, then it will require a concave glass to make the rays focus upon the retina; but as the rays passing in the examiner's eye must be divergent and not parallel, as in emmetropia, we will require a much stronger glass, so as to render the rays from the examined eye divergent, when they will focus upon the retina of the examiner. And we subtract the amount of the examiner's myopia from the glass used at the aperture, for the total myopia of the examined eye.

In the estimation of the refraction of an eye with the ophthalmoscope, you should also regard the distance at which the instrument is held from the examined eye; as,

although it will not make very much difference in the low degrees of refraction, yet, when you estimate the high degrees, as 10 D, or more, the distance at which the ophthalmoscope is held from the examined eye must be taken into consideration. You must hold the ophthalmoscope as close to the eye as possible, even until the instrument may touch the supraorbital ridge; and then, to make your examination scientifically correct, you should allow one inch, the distance of the ophthalmoscope from the nodal point. But in all your examinations, place your ophthalmoscope in just the same position as the glass of a pair of spectacles will be when properly adjusted, and then your examination with the ophthalmoscope will agree with the test by glasses.

In the high degrees of myopia, of 2, 3, or 4 inches, when the punctum remotum lies at such a short distance from the examined eye, an inch will make a vast difference in your calculations, as the fundus of the eye can be seen with a much weaker glass, when placed very close to the eye; and consequently, if you make your examination at two inches from the eye, your result will be an over-correction, or a much stronger glass than the actual degree of myopia. If you examine a myope with the punctum remotum, at, say, five inches from the eye, you must place the glass of the ophthalmoscope so that its negative focal point will agree with the punctum remotum of the examined eye; then, as the emergent rays pass through the glass, they will be parallel. The nearer the glass is to the punctum remotum, the stronger must be its refractive power.

The estimation of the errors of refraction by this direct method of examination is absolutely essential in the fitting of glasses, as well as in the study of all the finer details of the fundus. But in very high degrees of myopia, where the image is very large, or where we wish

to have a more general view of the fundus, I would advise you to use the *indirect method* of examination. It will be of service to you, and should be understood, although its results are so indefinite that you will find it serviceable in but few cases.

One of the best and simplest explanations of this indirect method of examination with the ophthalmoscope I find in "The Refraction of the Eye," by Gustavus Hartridge, F.R.C.S., third edition, and which I take the liberty to quote as follows:

"By the indirect method we obtain an inverted image of the disk by means of a convex lens placed in front of

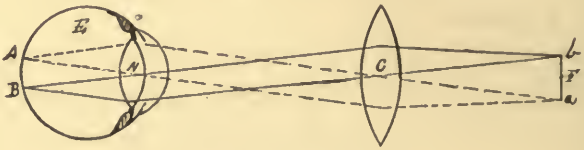


FIG. 50 (*Hartridge*).

the eye. In emmetropia (fig. 50) rays coming from *A* emerge from the eye parallel, and are focussed by the convex lens (*C*) at *a*, and rays coming from *B* are focussed at *b*; so also with rays coming from every part of *AB*, forming an inverted image of *AB* at *ba*, situated in the air at the principal focus of the bi-convex lens. In hypermetropia (fig. 51) the rays

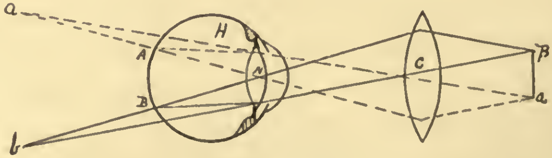


FIG. 51 (*Hartridge*).

from *A* emerge divergent; so also, of course, those from *B*. If these rays are continued backward, they will meet behind the eye (at the punctum remotum), and there form

an enlarged inverted image (*ab*) of *AB*. It is of this imaginary projected image that we obtain, by the help of the bi-convex lens, a final inverted image ($\alpha\beta$), situated in front of the lens beyond its principal focus. In myopia

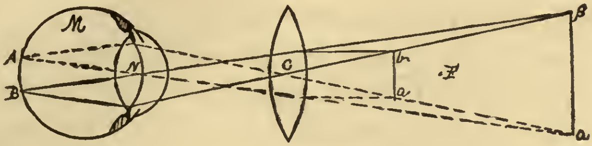


FIG. 52 (*Hartridge*).

(fig. 52) the rays from *A* and *B* emerge from the eye convergent, forming an inverted aërial image in front of the eye at $\beta\alpha$, its punctum remotum. It is of this image we obtain with a bi-convex lens, placed between it and the eye, a final image (*ba*) situated within the focus of the bi-convex lens.

"With this method we are able to detect the form of ametropia by the changes which take place in the size and shape of the optic disc, always remembering that the inverted image of the disc produced by a convex lens at a certain fixed distance from the cornea is larger in hypermetropia and smaller in myopia than in emmetropia. The lens should be held close to the patient's eye, and as it is gradually withdrawn, the aërial image of the disc must be steadily kept in view. The rapidity with which any increase or decrease takes place in the size of this image gives us an indication of the amount of the refractive error.

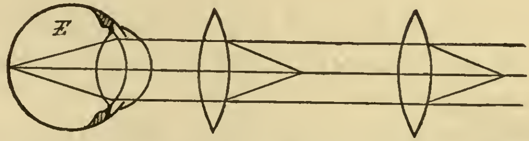


FIG. 53.—*E*. EMMETROPIC EYE; RAYS ISSUING PARALLEL; IMAGE FORMED AT THE PRINCIPAL FOCUS OF LENS, NO MATTER AT WHAT DISTANCE THE LENS IS FROM THE EYE.

"If no change take place in the size of the image on thus withdrawing the objective, the case is one of emmetropia, because rays issuing from such an eye are parallel, and the image formed by the object-glass will always be situated at its principal focus, no matter at what distance the glass is from the observed eye (fig. 53). As the relative distance of the image and the object from the lens is the same, the size of the image will also be the same.

"If diminution take place in the size of the image, the case is one of hypermetropia; and the greater the diminution, the higher is the hypermetropia.

"This change in size may be explained by remembering that in hypermetropia the image of the disc is projected backward, and it is of this projected image we obtain a final image with the help of the objective. The two dia-

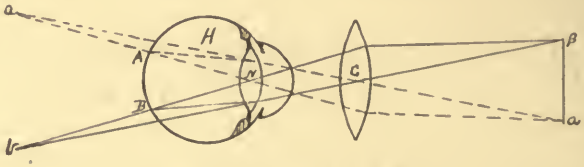


FIG. 54.—LENS AT 4 CM.

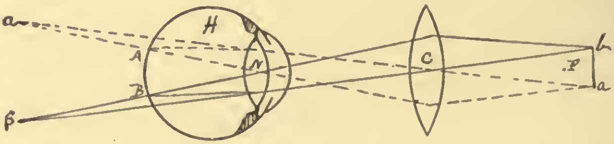


FIG. 55.—LENS AT 12 CM.; *H* HYPERMETROPIC EYE; *C* THE CENTRE OF THE LENS; *AB* IMAGE ON RETINA; *ab* PROJECTED IMAGE; *βα* THE FINAL IMAGE FORMED BY THE OBJECTIVE.

grams show images formed by the object-glass when held at 4 cm. and at 12 cm. from the cornea, the latter image being the smaller.

"The following explains this: The ratio of $\alpha\beta$ to ab varies directly as the length $C\alpha$, and inversely as the length Ca. On withdrawing the lens C from the observed

eye, $C\,\alpha$ diminishes and $C\,a$ increases; therefore the ratio of $\alpha\beta$ to ab diminishes,—*i. e.*, the size of the image diminishes.

"If the image become larger on withdrawing the object-glass, the case is one of myopia; the greater the increase of the image, the higher the myopia.

"This increase in the size of the image can also be explained with the help of mathematics, remembering that in myopia an inverted image is formed in front of the eye, and it is of this we obtain an image with a convex glass placed between the eye and the inverted image, which we must regard as the object; the object and its image being both on the same side of the lens.

"In astigmatism the disc, instead of appearing round, is frequently oval. If one meridian decrease while the other remains stationary as the objective is withdrawn, it is a case of simple hypermetropic astigmatism. If the whole disc decrease in size, one meridian diminishing more than the other, it is compound hypermetropic astigmatism, the meridian being most hypermetropic which diminishes most.

"Increase in one meridian, the other remaining stationary, indicates simple myopic astigmatism.

"Increase in disc, but one meridian more so than the other, indicates compound myopic astigmatism, that meridian being most myopic which increases most.

"If one meridian increase while the other decrease, mixed astigmatism is our diagnosis."

Such, gentlemen, is the description of the indirect method given by Hartridge, and you will find in some cases that this method will assist you in confirming the results of your examination by the direct method.

In closing this lecture, let me urge upon you the importance of the ophthalmoscopic estimation of refraction, as a means of confirming your examination with the trial

glasses. You must learn to relax your own accommodation completely, as well as the convergence of your optic axes, and, if not able to do so, find out how much you can relax. You should do this by means of some very small (diamond) type placed at the focal point of a bi-convex lens, at which distance you should read it easily through the lens; and if you cannot completely relax your accommodation, you may use a concave lens that will adapt your eye to parallel rays. You will also find it almost impossible to relax the accommodation in the examination of low degrees of hyperopia, unless the student should be past the meridian of life; but I do not think that, with practice, you will have much difficulty in the estimation of hypermetropia, as you place the convex glass at the aperture of the ophthalmoscope.

SEVENTH LECTURE.

MUSCULAR ASTHENOPIA.

Primary and secondary position of the eyeball—Axis of rotation—Action of muscles—Diplopia—Insufficiency—Test for—Strabismus—Convergent—Concomitant—Amblyopia in squint—Paresis or paralysis—Angle of strabismus—Test with prisms—Projection of image—Homonymous diplopia—Crossed diplopia—Apparent squint—Angle "α"—Objective examination for squint—Test for the angle of strabismus and the angle "α"—Periodic squint—Deviation of the images in diplopia—Refraction of prisms—Angle of deviation—Principal angle of a prism—Table of paresis of muscles—Insufficiency or paresis of the superior or the inferior rectus—The oblique muscles—Test with prisms—To test each muscle—Landolt's ophthalmodynamometer—Method of using—Ordering prisms—Decentred glasses.

Gentlemen :—You will remember that in our lecture on anatomy we found that the eyeball was moved in different directions by the action of the ocular muscles, either singly or combined; also that, by the action of these muscles, the eyeball was turned on its centre of rotation, a point lying upon the optic axis of the eye, about 14 mm. behind the cornea. This is practically a fixed point, around which the outer portion of the eyeball moves by the action of the several ocular muscles.

We have also seen that these six muscles form three pairs, antagonistic to each other, which, by their inherent tonicity, when in a state of rest, tend to keep the eyeball directed forward, the optic axes almost parallel, and at an inclination of 15 degrees below the horizontal plane, so that the rays of light from a distant point fall directly upon the macula lutea. This is called the *primary position.* Then, with the visual axes parallel to each other, or converging toward any point, we may move the

eyes simultaneously to any other point. The eyes are then in the *secondary position.*

Now you will readily see that, by the action of the ocular muscles, both eyes must work in unison, and, consequently, should any muscle fail in its duty, the visual line of that eye to which such muscle belongs will be changed, and the rays of light from a given point will fall upon different parts of each retinal field. The vision will be very much blurred in one eye, with distinct diplopia, or double vision, and the images separated according to the degree of displacement of the optic axis. Then should any of these ocular muscles become weak, or its nervous supply be not up to the standard (a paresis), one eye will occupy the primary or correct position, while the other eye will be moved in an opposite direction from the weakened muscle.

We know that the eyeball turns around the centre of rotation, but, as it is moved in various directions, it is also turned on certain *axes of rotation*, each of which passes through this centre of rotation.

First, we have the *vertical* axis, around which the eye is turned by the rectus internus and rectus externus, turning the visual axis inward or outward, as the muscles may act.

The next axis lies in the horizontal plane, around which the globe moves, and the visual axis is directed upward or downward by the action of the superior and inferior rectus. This axis is not strictly transverse, or at right angles to the mid-plane of the body; but its nasal extremity lies rather forward, so as to form an angle of 67 degrees from the visual axis. From this position, and also as the points of origin of the rectus superior and inferior are much nearer the median line of the body than their points of insertion on the globe, they would also tend to act in conjunction with the internal rectus, so as to make the visual axes converge.

The oblique muscles, taking their point of action from the region of the inner canthus, both acting from points on the same line, would tend to turn the eyeball upon an axis, the anterior extremity of which lies at an angle of 37 degrees outside of the visual axis. (See fig. 6, page 11.)

You will then understand that the simple movements of the ocular muscles, acting singly, would tend, first, by the internal and external rectus, to turn the cornea outward or inward; that the superior and inferior rectus will direct the cornea upward or downward and slightly inward; while the action of the superior and inferior oblique, rotating the globe on its axis, would tend to turn the cornea, by the superior oblique, downward and outward, and by the inferior oblique upward and outward, at the same time turning the globe on its own axis. The combined movements of any of these muscles will tend to turn the globe in any direction, each eye acting in unison with its fellow, and keeping the visual axes directed upon a single point.

If, then, any single muscle, or group of muscles, be unable to keep the visual axes in their proper position, from weakness of the muscular structure, or a paresis of its nervous supply, you will find that the visual axes will not correspond, that the globe of one eye will not move as quickly and readily in all directions as its fellow; while in paralysis of any of these ocular muscles there will be complete cessation of motion, a turning of the globe in an opposite direction to that of the action of the affected muscle, with consequent strabismus.

When these muscles are weakened from any cause we have slight diplopia, perhaps only at the reading distance; any deviation of the globe will not be noticed. Nor are there any obvious symptoms of this condition; but, if we have a slight paresis, or weakness, of any one of the ocular muscles, not sufficient to cause squint, you can readily

see which muscle is affected by causing the patient to follow the movements of a pencil or the finger, when held at different positions, in front of the eyes. Then, if any muscle fail to act properly, the cornea will lag behind the movements of its fellow in the other eye.

Strabismus, or squint, with or without diplopia, is the most frequent and common condition of insufficiency of the ocular muscles. It usually occurs as either a convergence or divergence of the optic axis, and may be due to different causes.

You will remember that, when speaking of the hypermetropic eye, and the relative variety of hypermetropia, we found that many children learn to squint, because, from their high degree of hypermetropia, they see more clearly by convergence of the visual axes, showing first a periodic squint, and then a condition of permanent or fixed squint. This condition is known as *convergent concomitant* strabismus, in which the convergence of the visual axes seems fixed in one position. If the right eye be fixed upon an object, the left one will be turned inward; and if the left eye is fixed, the right will turn inward; but the patient will always fix one eye upon the object, and keep the other eye turned inward or outward.

In nearly all cases of fixed strabismus, we have one eye highly amblyopic,—it is always the squinting eye; while the refraction of both eyes will be hypermetropic, from a moderate to a high degree.

The cause of the amblyopia in the squinting eye is still a matter of doubt; at one time it was supposed to be due to non-use of the retinal elements, and suppression of the image on the retina. This theory is still held by some oculists; but I am inclined to think that the condition of amblyopia is congenital, and that, from the inability of the eye to fix its visual axis upon an object, due to the non-stimulation of the rays of light, the eye turns inward. (See

Lecture on Hypermetropia.) No matter how early in life we test the vision, we find one eye more or less amblyopic, and no resultant improvement in the sight by the use of glasses.

I am led to this conclusion, because I have seen some cases of hypermetropia in which there was amblyopia of one eye, so that the vision was reduced to $\frac{20}{100}$, and no improvement with glasses ; yet there was no strabismus, nor did the ophthalmoscope reveal any evidence of abnormal condition of the retina or refractive media except the hyperopia.

We may classify the causes of stabismus in three varieties : first, congenital amblyopia ; second, relative hypermetropia, with or without amblyopia (*amblyopia ex anopsia*) ; and, lastly, paralytic strabismus, which latter I hardly consider suitable for discussion in this work, though, should it cause a slight but annoying diplopia, it may be relieved by suitable prisms.

Now, though we have this convergence of the visual axes, with a fixed squint in one eye, yet you will notice that the excursions of the eyes are not diminished, but move freely in all directions, unless there be a paresis, or perhaps complete paralysis of one of the external muscles of the globe.

Let us test this, to see if the movement of the eye be perfectly normal in all directions. If we cover one eye with the hand or a screen, the uncovered eye will readily follow the movements of an object in any direction. It is then evident that there is no insufficiency or paralysis of the ocular muscles, as should there be insufficiency the eye will lag behind in certain directions ; while, should there be a paresis, the excursions of the eye will be limited ; and in complete paralysis the eyeball will not move in the proper direction through the non-action of the paralyzed muscle.

The diagnosis of fixed squint is quickly made, but in the cases of periodic squint, or insufficiency of the ocular muscles, you must cover one eye of the patient with the hand or a screen, and watch the movements of the other eye. But, to make your examination correct, you may measure the *angle of strabismus*, which Landolt gives as "the angle which the visual axis of the deviating eye forms with the direction it should have in a normal position."

To determine this angle objectively, Landolt uses the arc of a perimeter with the deviating eye placed in the centre of the arc, and the other eye fixed on a distant object, as shown in this diagram.

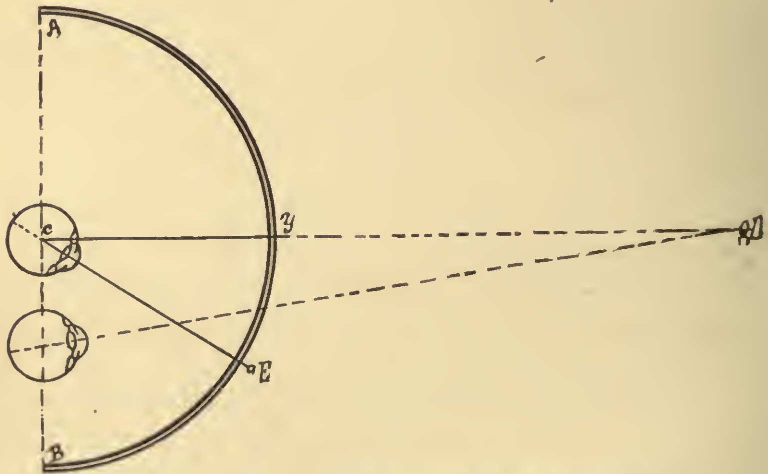


FIG. 56.—METHOD OF TESTING THE ANGLE OF STRABISMUS.

If the deviation of the eye be in a lateral direction, we place the arc of the perimeter horizontally, with the deviating eye *C* in the centre of the arc *AB*, and the vision of the other eye fixed upon the object placed at the point *D*. Then the line *CYD* will be the direction which the visual line of the squinting eye should have. If we then move a candle along the arc from the point *Y*, with

the eye of the examiner directly behind it, until we can see the image of the candle directly in the centre of the cornea, which in this case would be at the point E, the reflection being exactly at the anterior pole of the eye and upon the optic axis, then the optic axis must be in the line CE, which forms an angle with the proper direction of the visual line. The angle YCE is the angle of strabismus, and the number of degrees on the arc of the perimeter will give us the degrees of this angle. The line CE is the optic axis, and as the visual line differs so slightly, we may omit it from our calculation (see the angle a), and consider the optic axis and the visual line as the same.

Let us now take up the diagnosis of those slight cases of insufficiency that will cause fatigue at close work, or a slight diplopia at both near and far distances.

This condition is not readily perceptible to the eye, and we must depend upon our subjective examination, which must be conducted by the test with prisms, and upon the statements of the patients.

You well know that the action of a prism is to bend all rays of light toward the base. Then, if we place a prism of about ten or twelve degrees with the base directly upward, before either eye, it will deflect the rays of light from an object passing in that eye so far upward that the rays will strike the retina above the macula, and the image will be seen below, while those passing in the other eye will strike upon the macula. As these two images will be upon different parts of the retina of each eye, they will be seen, one above the other.

Now having rendered the eye unable to respond to that stimulus, the eyes have to direct the visual axes to a single point by causing the rays to fall upon different parts of each retina; then, if there be any weakness of either the internal or external recti, the object will not only be seen

one image above the other, but you will also find that the images are displaced laterally, according to the amount or degree of insufficiency of the weakened muscle.

We must find out which muscle is weakened, and to do so we use the flame of a candle as our test, placed at 15 or 20 feet distant. Now place a disc of red glass over one eye, making the image of that eye appear red, and then notice in what position the patient will see the two images and the position of the red light when looking at the flame of the candle with both eyes.

If you find that the red light is not only above, but is displaced laterally and on the same side on which the eye is where you have placed the red glass, we have *homonymous* diplopia, due to an insufficiency of the external rectus muscle of one eye.

Now, to prove this, we know that when the rays of light from the flame strike the retina above the horizontal plane, they are projected downward, so that the image will be seen below; while if the rays fall upon the retina below the horizontal meridian, they will be projected upward. Then if the rays strike the retina *outside* the vertical plane, drawn through the macula, they will be projected *inward;* while if they strike *inside* the vertical plane, they will be projected *outward.*

If, then, we find that the red image is on the same side as the eye over which the red glass is placed, we must have an image that is projected outward. To cause this, the rays must strike the retina inside the macula. Such being the case, why do the rays fall upon the retina at that point? Because, as the eyeball turns upon its centre of rotation, the posterior portions of the globe will move outward as the cornea moves inward; and as the rays pass in straight lines they must fall upon the retina on the inside of the macula.

In this diagram (fig. 57), which represents the hori-

zontal plane, with the right eye at *C*, and the left at *A*, you will notice that the eyeballs turn on their centres of rotation *y*. If, then, the visual line of the right eye *C* be fixed upon the light at *B*, its visual line will pass from the macula *m* to the light *B*; but in the left eye the visual line will be turned inward, as represented by the dotted line *mD*, and the rays of light from the object placed at *B* must fall upon the retina of the left eye *A* at the point *o*, inside the macula.

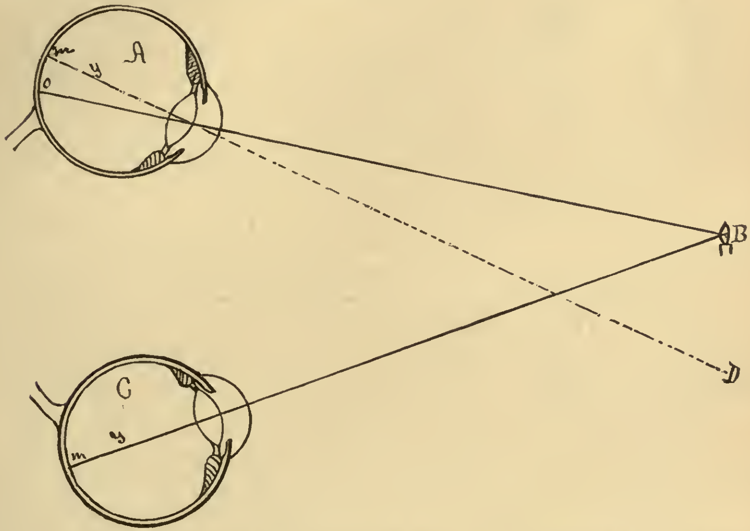


FIG. 57.—DIAGRAM SHOWING POSITION OF MACULA : CONVERGENT STRABISMUS.

The only muscle, the failure of whose action will allow the eyeball to turn inward, is the external rectus; so in this condition of homonymous diplopia we must have a weakness of one of the external recti muscles.

Let us now examine a case in which the red light is seen by the person upon the opposite side from the eye over which we have placed the red glass. We now have *crossed* diplopia, because the image to the right is seen by the left eye, and that to the left by the right eye.

Then the rays from one eye must be projected in-

ward, so as to make the image on the opposite side ; and if so, the rays from the candle flame must strike the retina on the outside of the vertical plane, drawn through the macula. Consequently, when the rays fall upon this part of the retina, the image is projected inward and is seen on the opposite side. To produce this result, the cornea must be turned outward, so as to allow the posterior portions of the globe to rotate inward.

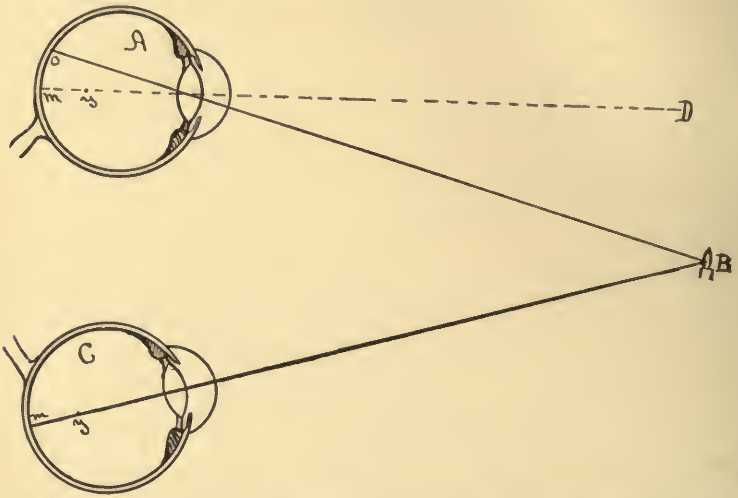


FIG. 58.—DIAGRAM SHOWING DIRECTION OF VISUAL LINE : DIVERGENT STRABISMUS.

If we look at this diagram (fig. 58) in the horizontal plane, we find that the left eye is turned outward on its centre of rotation *y*, that the visual line from *m* to *D* is turned the same way, from the object or light placed at *B*, and that the rays from the point *B* fall upon the retina of the left eye *A* at the point *o*, outside the position of the macula *m*, while the rays passing in the right eye *C* fall directly upon the macula.

There is only one muscle which will allow the eyeball to turn directly outward, from insufficiency or paresis, and that muscle is the internal rectus, being overcome by the power of the external rectus. The direction of the visual

line is then outward. This condition must cause crossed diplopia, in which we have an insufficiency of one of the internal recti muscles.

You may meet with some persons that have an apparent squint, but in which the visual axis of each eye is fixed upon the object, while the images are formed upon the retina at the macula lutea; although, from an objective examination the eyes may appear crossed or divergent, as regards the direction of their optic axes.

This will be due to the size of the "angle *a*," which is formed by the crossing of the optic axes and the visual line, at the nodal point of the eye.

The optic axis passes directly from the centre of the cornea, at the anterior pole, to the centre of the back part of the globe, at the posterior pole, passing through the nodal point, near the posterior surface of the lens; while the visual axis, passing from the macula, through the nodal point, to the object, will cut the cornea inside the anterior pole.

Let us illustrate this by a diagram, in which is represented a horizontal section of an eyeball.

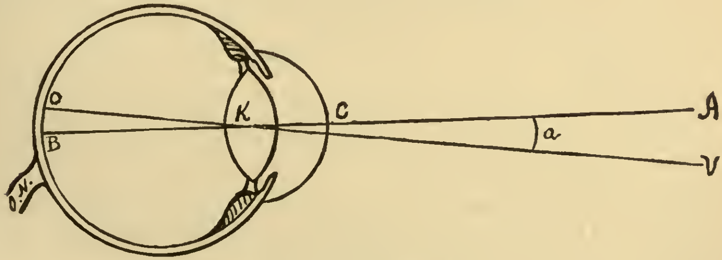


FIG. 59.—THE ANGLE α.

The line *A B* represents the optic axis, which lies nearer to the entrance of the optic nerve than the macula lutea, at *O*, while the visual axis is represented by the line *V O*, which passes from the macula at *O*, through the nodal point *K*, situated on the optic axis, then through the cornea, inside the anterior pole to the object *V*, these

two axes forming the angle α, with the apex at the nodal point.

Now the position of the macula, in reference to the posterior pole of the eye, will limit the size of the angle α, as the greater the distance, the greater will be the size of the angle. We designate this angle by degrees, and when the posterior pole lies between the nerve entrance and the macula, as in this instance, we call the angle α positive, or +; while in cases of myopia of high degrees, with a corresponding increase in the length of the globe, the macula comes so much nearer the nerve entrance that the visual line passes out, through the cornea, on the outside of the optic axis, and the angle α becomes negative or —.

Now in high degrees of hypermetropia the angle α may equal 7° or more; while in emmetropia it is only about 3°, and in myopia it is still smaller; then as we pass to the still higher degrees of myopia, the angle α disappears, until we find it on the inside of the posterior pole, when it becomes—,or negative. This has been proved by Landolt in the examination of over one hundred eyes during life, and from this fact you will understand why in certain cases of refraction we may have an apparent squint, either convergent or divergent, of slight degrees, while both visual axes are fixed upon an object. In myopia you may have an apparent convergent squint, and in hypermetropia an apparent divergent squint.

Let us now diagnose a case of squint, and decide whether we have to deal with a real squint, due to the contraction or insufficiency of one of the recti muscles; or only an apparent squint, due to the increased size of the angle α.

You will first cover one eye of the patient with the hand or a screen, so as to remove the stimulus of the visual impressions on the retina of that eye. Then, if there be an insufficiency of any of the ocular muscles, the

covered eye will turn in the opposite direction ; while, if the squint be only apparent, both eyes will remain in their fixed position, as the visual axes are directed to a point 18 or 20 inches in front of the eyes.

Should you wish to be much more exact, and decide just how many degrees of variation you may have by the angle α, or in slight degrees of squint (see fig. 56), you may use the method published by Landolt's assistant, Charpentier, in the *Annal. d'Ocul.*, January, February, 1878, as follows: "The deviating eye is placed at the centre of the perimeter (fig. 60), at *O*; on a line with it is placed a small flame, which the patient must fix with both eyes; the observer now moves along the graduated arc, the flame remaining in its place, until he sees, with one eye, the reflection of the flame at the apex of the cornea of the deviating eye. The angle which is thus formed is double the angle formed by the optic and visual

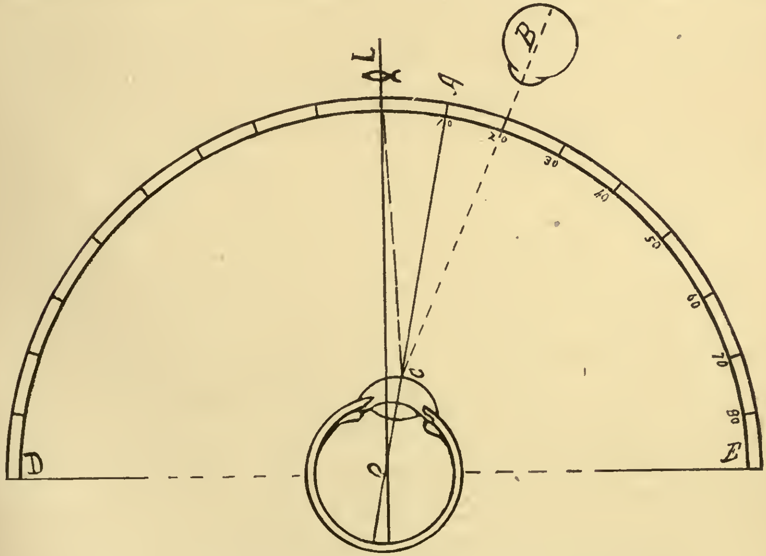


FIG. 60.—DIAGRAM SHOWING THE ESTIMATION OF ANGLE α.

axes. In this diagram, *O* is the deviating eye, which should, in its normal position, be directed toward *L*, but is now

directed toward A; the angle $A\ O\ L$ is the angle α. The eye of the observer, at B, will see the reflection of the flame L from the centre of the cornea, when the ray $L\ C$ will be reflected from the cornea at an angle equal to the angle of incidence $L\ C\ A$. This last angle is almost the same as the angle $L\ O\ A$, which is the angle of the strabismus, and is one half of the angle $L\ C\ B$."

The angle α is measured in the same manner. You have the examined eye in the centre of the perimeter, but with the visual line fixed upon the candle at L, that the eye may see the flame clearly; then the point at which the reflection of the candle is seen on the cornea will give the position of the anterior pole, and the direction of the optic axis, a point on the arc of the perimeter midway between the flame and the eye of the examiner. Then, if the line $L\ O$ is the visual line, and the line $A\ O$ the optic axis, the angle $L\ O\ A$ will represent the angle α, which, expressed by degrees, will be one half the distance between the points L and B on the arc of the perimeter.

There are also cases of strabismus where it is not apparent, except when the eyes are used for close work, as reading, etc. This condition is called *periodic squint*, and is generally associated with relative hypermetropia. We find the vision perfect in one or both eyes, the stimulation of the rays of light falling upon each retina will be great enough to enable each eye to fix an object. But when either eye is covered with the hand or screen, the uncovered eye will turn inward, from the withdrawal of the stimulation of the rays. In such cases you will find that the selection of the proper glasses, or perhaps a slight tenotomy, on the side opposite to the weakened muscle, and on the eye with diminished vision, will relieve all tendency of the eye to converge.

Marked strabismus will seldom cause diplopia, or double vision, as the rays that fall upon the retina of the squint-

ing eye form an image upon the less sensitive parts, which the patient soon learns to suppress ; but, in cases of insufficiency of any one of the ocular muscles, the images will be formed, one at the macula, and another so near that region that the double vision will be very distressing.

The principal complaint that the patients will make is that the letters seem to be double, with one superimposed on the other, not as they have in asthenopia from weakness of the ciliary muscle, when the letters all appear blurred and indistinct.

These slight cases of insufficiency, or paresis, of the ocular muscles are not so readily detected by the objective symptoms that we have been discussing, except at the extreme limits of the field of fixation. You may test them in this manner : You should have the patient to follow the movements of a pencil held in the hand, and moved in every direction as far as the eye can possibly follow it. You will then notice if at any time the eye wavers in its movements at the limits of the excursions, and if so, the muscle which controls it in that direction will be the weak or insufficient one.

As this simple test will not answer in some cases, you will proceed to test them first at the near point, or the reading distance of about 12 to 15 inches. For this purpose take a piece of white card-board about 4 by 8 inches ; through the centre of this draw a line downward the entire length of the card, and in the centre of the line place a round dot about one-fourth of an inch in diameter. Now place a prism of 12°, with the base upward, over one eye, and hold the card so that the line will be vertical, and in the median line of the face. The patient, if there be no insufficiency, will see only one long line ; but with two dots the internal and external recti will tend to keep the vertical plane of each eye in its primary position.

Now, if we find that the person sees two dots and two lines, it is very evident that either the external or the internal rectus of one eye must be insufficient to keep the vertical planes in their positions, and the images will be apart. Then the prism placed over either eye, with the base inward, which will cause the patient to see one line and two dots, will show the degree of insufficiency of the internal rectus; and with the base placed outward, to produce the same result, insufficiency of the external rectus.

The false image, or the one that is seen with the squinting or deviating eye, is projected outward or inward as the case may be, according to the position in which the rays from the object strike upon the retina. I have explained to you, in the previous part of this lecture, that,

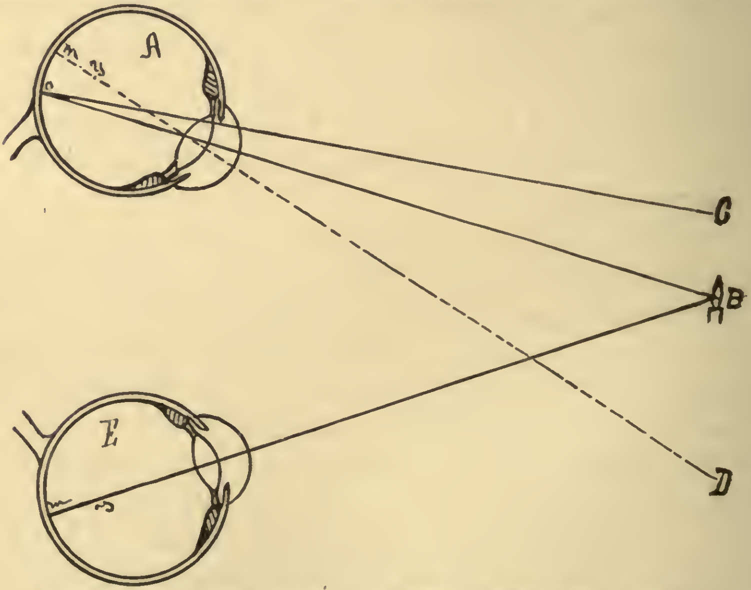


FIG. 61.—THE PROJECTION OF THE IMAGE: HOMONYMOUS DIPLOPIA.

when the image is above the macula, the object will appear below; while, if below the macula, it will appear above. A similar result obtains in the lateral images, as

the image will then appear outward when the rays fall upon the retina inside the macula, and inward when they strike outside the macula.

In the above diagram the object *B* is seen distinctly by the right eye *E*, as the visual line *Bm* passes directly to the macula at *m*, while the visual line of the other eye *Dm* is turned inward, being directed toward *D*; consequently, as the eye is turned on its centre of rotation *y*, the rays of light from the object will fall upon the retina at the point *o*, inside the macula. It will then be projected outward on the same side as the deviating eye, and the object will appear at *C*, as shown by the line *oC*. The distance between these two images will be regulated by the degree of deviation and the distance at which the object is placed from the eyes. The greater the distance at which the object is placed, the greater the distance between the images, while the angle of the strabismus will remain the same.

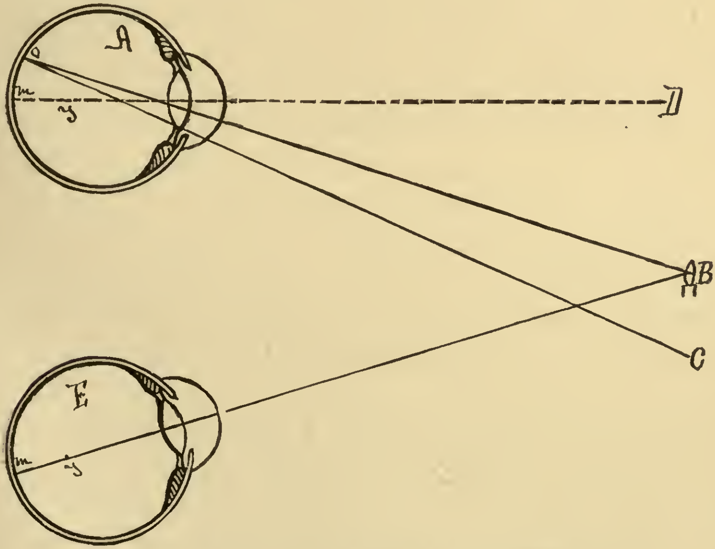


FIG. 62.—THE PROJECTION OF THE IMAGE: CROSSED DIPLOPIA.

In this diagram the object *B* is seen distinctly by one

eye, but on the opposite side from the deviating eye. We see that the visual line passes directly from the object *B* to the macula, *m*, of the right eye, *E*, while the visual line of the other eye, *Dm*, is deviated to *D*, as shown by the dotted line, and consequently is turned outward on its centre of rotation, *y*. The rays of light from the object *B* fall upon the retina at *o*, outside the macula *m*, and are projected inward on the opposite side, and are seen at *C*, as shown by the line *oC*. The image to the right, *C*, is that of the left eye; and the image *B*, that of the right eye.

This condition is called crossed diplopia, from the images being on opposite sides. It is always associated with a weakness or paresis of the internal rectus, *strabismus divergens;* while, if the image is seen on the same side as the deviating eye (fig. 61), we have homonymous diplopia. This is due to a fault of the external rectus, causing *strabismus convergens.*

The image that is formed in the region of the macula of the deviating eye in the direction of the line *mD* (figs. 61 and 62), will not attract the patient's attention; but if it does, it will not appear distinct. In most cases of squint we have the condition of amblyopia; so that the image formed by the deviating eye will not be distinct, and is easily suppressed.

In nearly all cases of squint, unless of very slight degree, they are not troubled by the diplopia, as they have learned to suppress the image of the squinting eye, and monocular vision results.

It is possible that you may have *monocular* or *uniocular* diplopia, a very rare condition, that may be due to changes in the crystalline, as commencing cataract, irregular curvature of the cornea, displacement of the lens, or in cerebral tumors, and should be examined very carefully. (NETTLESHIP.)

These various tests that we have applied to our patient will prove that we have either an insufficiency or paresis of one or more of the ocular muscles ; but it does not show us which muscle may be affected, nor to which eye it belongs. We shall have to proceed further in our examination before we can decide how to apply any correcting glass, or adopt any other means for the relief of the diplopia.

This brings us to the study of the action of prisms upon a ray of light, and how prisms may correct the diplopia.

You will remember that when speaking of the refraction of rays of light, as they pass through different media, we have found when passing through a prism, they are bent or refracted toward the base. The theory you will find in the second lecture.

Now the amount or extent to which these rays are refracted will depend upon the principal angle of the prism, and the angle of deviation will be, for weak prisms, one-half of the principal angle. The prisms that you find in our trial cases are marked with numbers, which represent the principal angle, and consequently the angle of deviation will be one half of that number. If a prism be marked 20°, this number will represent the principal angle in degrees, and the angle of deviation will be only 10 degrees. Then the deviation of the visual line, when a diplopia is corrected by a prism marked 20°, will represent a deviation or squint of 10°, outward or inward, as the base of the prism is placed.

By the angle of deviation, we mean that angle which is formed with the line of incidence, in this manner :

The ray of light passing from an object *a*, strikes the prism in its primary direction at *B*, and is bent toward the normal, as shown by the dotted lines at the point of contact. Crossing the prism to the point *C*, it now

emerges in a direction from the normal, and passes to the point *o*. Then, to cause these rays to fall upon the retina at the macula, the eye, placed at the point *o*, must have its visual axis in the direction of the line of emergence, *oC*, and the object will appear to be placed at a^1. This line oCa^1, with that of the line of incidence *AB*, when they meet at the point *N*, will form the angle of deviation *D*, which will be one half of the principal angle *E* of the prism. Consequently, while the rays passing through a prism will be bent toward the base, we find that the deviation of the object will appear toward the apex, from *a* to a^1.

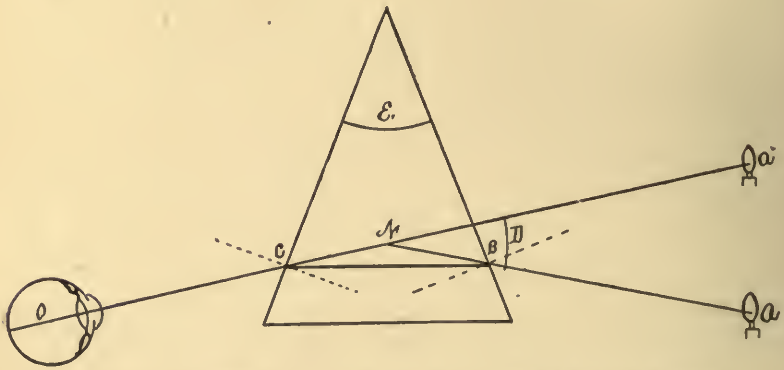


FIG. 63.—THE ANGLE OF DEVIATION AND THE ANGLE OF PRISM.

We will now proceed to the practical part of this work, *i. e.:* How we shall use the prism to measure the degrees of squint or diplopia, or to estimate the insufficiency and the power of the ocular muscles.

In a case of diplopia, due to a paresis or insufficiency of any one of the ocular muscles, you should first test them at a distance of 20 feet, using the flame of a candle as your test object. Now if the diplopia be constant they will see two flames, placed from each other, according to the muscle that may be affected. If the internal or external rectus, the flames will be displaced laterally; if the

superior or inferior be affected, the flames will be displaced, one vertically above the other; and in the case of the oblique muscles you will find the flames one above the other, and also displaced laterally; at the same time, one flame will be inclined to one side.

As regards the frequency of each of these conditions, I find that, according to Landolt "On the Examination of the Eyes," Von Graefe has recorded 183 cases of paralysis of the muscles of the eye; and that where the paresis was isolated, there were:

105	paralyses	of external rectus.
52	"	of superior oblique.
10	"	of inferior rectus.
9	"	of superior rectus.
5	"	of internal rectus.
2	"	of inferior oblique.

We learn from these tables that the largest number of cases of paresis are the external rectus and the superior oblique, two muscles which have a separate and distinct nervous supply; the external rectus, being controlled by the sixth cranial nerve or abducens, and the superior oblique by the fourth cranial nerve or patheticus. All the other muscles of the eye are controlled by the impulse of the third cranial nerve, the motor oculi. When an isolated muscle of this group is deficient in its movements, it is due to a paresis of one of the filaments of this third nerve, which supplies the affected muscle.

In the case of a patient who complains of diplopia, we will first place a disc of red glass over one eye, and then note the position and inclination of the two flames, as seen by him, one being colored red by the glass. Then, if they are displaced laterally, and the red light is seen on the same side as the eye over which we have placed the red glass, we have *homonymous* diplopia. But, if the red light is on the opposite side, we have *crossed*

diplopia. If we have a paresis of the superior or the inferior rectus, we will have the flames superimposed. When the superior rectus is affected, the flame seen by that eye will be above, and slightly crossed ; while, if the inferior rectus is at fault, the flame seen by the affected eye will be below and slightly crossed, this crossing of the images being caused by the action of the internal rectus muscle.

Should you meet a case of complete paralysis of the motor oculi, you will find crossed diplopia ; the eye restricted in its movements, inward, upward, and downward ; slight prominence of the eyeballs ; the upper lid falling ; the pupils dilated and immovable, and the accommodation paralyzed,—a condition very similar to that of *ophthalmoplegia externa*, where we have all the external and internal muscles of the eye paralyzed, with the eyeballs very prominent, from the loss of the natural tonicity of the recti muscles.

As we proceed in our examination, we have probably decided which muscle is affected ; but we will now endeavor to locate it, and find out the degree of insufficiency. This we will do by placing prisms before one eye, using a stronger one each time, until the flames are brought together and appear as one, always placing the base of the prism over the muscle that is affected, and the red glass over the other eye.

Let us illustrate this with a case, in which we have a paresis of either of the external recti, with slight squint and homonymous diplopia. If the eye turns inward on its centre of rotation, the macula must be carried outward, and consequently the direct rays from the candle will fall upon the retina inside the macula, and, being projected outward, will cause the images to be homonymous. You will then place the prism before one eye, with the base over the weakened muscle outward, so that, as the deviated rays will be bent outward, they must

fall upon the macula. When we have used a prism of a known degree, and strong enough in its refractive power to fuse the images and make them appear as one, we will have the degree of insufficiency.

Then when only one flame will be seen, the number of the prism, divided by 2, will give you the degree of deviation of the eye and its visual line, which in this case, if if we use a prism of 20° principal angle, will show a deviation of the visual line from the normal of 10°, and the angle of deviation will be the same when measured by the perimeter. (See figs. 56 and 60.)

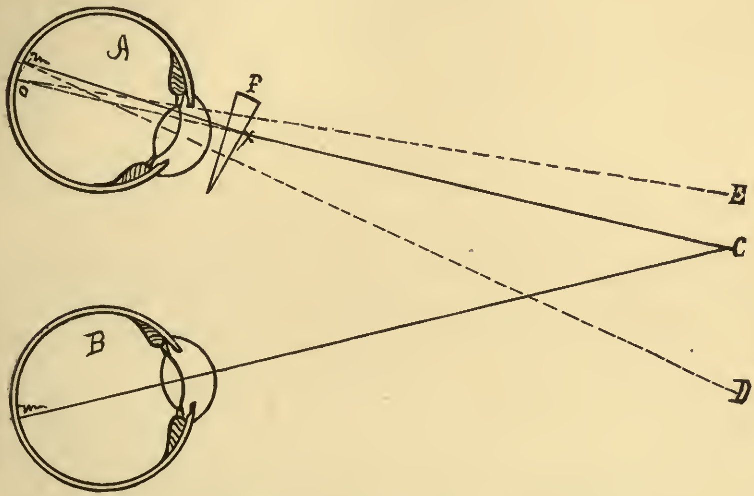


FIG. 64.—ACTION OF PRISM IN HOMONYMOUS DIPLOPIA.

The theory and reason for placing the base of the prism over the affected muscle are shown in the diagram. When the rays of light coming from the object at the point *C*, and passing into both eyes, *A* and *B*, will in the the right eye, *B*, fall upon the macula, *m*, but in the left eye, *A*, being turned inward, with the visual line at *Dm*, the rays will fall upon the retina at *o*, a point inside the macula, *m*, and be projected outward to *E* with homonymous diplopia. But if we place the prism *F* over

the eye *A*, with the base outward, the rays of light from the luminous point, *C*, will be deviated at *X* by the action of the prism. When you have selected the proper glass, you will find the images of each eye fused, when single vision results. Then the degree of the prism which will fuse the images will be double the number of degrees that the eye *A* is deviated inward from the proper position when fixed upon the object at *C*.

Should you find a weakness of any of the other muscles, you will proceed to test them in the same manner as we have tested the external rectus.

This method of examination will show us that we have a case of insufficiency of one of the external recti muscles; or both may be affected. Then, to find out which individual muscle is affected or deficient in its muscular power, we must proceed to test each muscle separately in the following manner.

As a prism bends a ray of light toward its base, then if we place a prism before the eye we will bend the rays entering that eye, either outward or inward, according to the position of the base. Then, as the eye naturally objects to the diplopia produced, we will, by the action of the muscles, turn the direction of the optic axis either outward or inward, until the rays passing in each eye fall upon the macula.

Now, if we wish to test the strength of the external rectus muscle individually, to find what is the strongest prism it can overcome, you will place before one eye a prism of a low degree, say about 2° or 3°, with the base inward, as this will bend the rays inward; the external rectus of the same eye must turn the cornea outward, so as to cause single vision. Then the strongest prism that can be placed before the eye, with the base inward, will show the power of that muscle to turn the eyeball outward. In this manner we may test the relative strength

of each muscle, as represented by the degrees marked upon each glass, taking the strongest that the muscle can overcome and still have single vision.

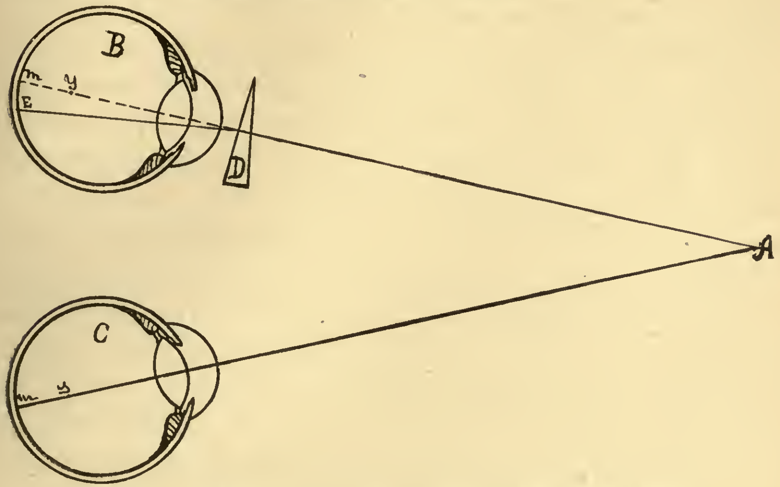


FIG. 65.—METHOD OF TESTING THE MUSCLES WITH PRISMS.

Let us illustrate this with our diagram, in which the rays from the object *A* fall upon the macula of each eye at *m*, but, with a prism before the left eye, as at *D*, with its base inward, the rays will be bent toward *E*. Then, to bring the macula at *E*, the eye *B* must rotate on the vertical axis, at *y*, outward. This action is produced by the external rectus, and the stronger the prism the greater must be the efforts of the muscle to rotate the eye outward. Hence the strongest prism by which the person examined still has single vision will represent the power of the muscle to act.

In this test of the strength of the recti muscles you will find them different in power, according to the purposes for which the eyes are used, viz.: the internal rectus is the strongest, next the external rectus, and lastly the superior and the inferior rectus. The standard power of the internal rectus is about 25 to 35 degrees; *i. e.*, there will be single vision with a prism of that number of de-

grees, placed before the eye with its base outward. The power of the external rectus will be about 8 degrees, that of the other muscles about 3 or 4 degrees, the inferior being generally the strongest.

If, then, we have a case in which the action of the muscles, when tested separately, cannot overcome the deviation of a prism of the above refractive power, we may be sure there is a deficiency of the muscle tested, though there may be no diplopia; but the muscle power is not great enough to do the work required, at the usual occupations of life.

Prof. E. Landolt, of Paris, published, in the *Ophth. Review*, vol. v., Nos. 57 and 58, July and August, 1886, a monograph, translated by W. T. Law, M.D., F.R.C.S., "On Insufficiency of the Power of Convergence," in which he proposes a new and excellent test for the power of the internal recti muscles, acting together, showing their power with binocular vision, at different distances, by means of an instrument, which he calls the *ophthalmo-dynamometer*. It is described as follows: "This little instrument consists of a cylinder which can be fixed to any candle of ordinary size. It possesses a vertical slit of about three *mm.* in breadth, a vertical line consisting of a series of fine openings, and a circular aperture of about one *mm.* in diameter. The openings are all covered with ground glass, and when the candle is lighted they form shining objects, thrown into sharp contrast with the blackened exterior of the cylinder. Under each opening is placed a hook to which can be attached the end of a measuring tape, constructed to wind up by a spring in the ordinary way. This tape is divided into centimetres on one side, beginning from its free end, and on the other side into corresponding value in metre angles or dioptrics, as the case may be.

"To ascertain the maximum of convergence, the tape

being partly withdrawn, its case is held at the outer margin of the orbit, so that the aperture through which the tape issues is on a level with the point of rotation of the eyeball. The patient is then told to look at the vertical line upon the cylinder, and the instrument is gradually brought nearer, in the median line, until he says the line appears double (crossed diplopia). The measure is then removed, and the distance of the punctum proximum read off on one side of the tape, and the maximum of convergence upon the other."

In describing the use of this instrument, to measure the power of convergence, we must take as a standard of 1 a *metre angle.*

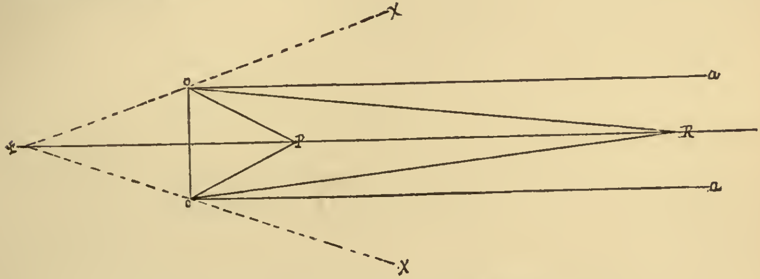


FIG. 66.—DIAGRAM SHOWING THE METRE ANGLE.

This metre angle is formed by the base line, in the above diagram, at *o a*, in passing from infinity to the nodal point of the eye at *o;* then, if the eye is directed to the point *R*, on the median line, at one metre from the eye, the visual line, *o R*, with the base line, will form the angle *a o R*, which will be one metre angle. As we bring the object *R* nearer to the eyes, in the median line, this angle will increase in size, and the visual axes become more and more converged. Then, according to Landolt, we find "that the angle of convergence is in inverse proportion to the distance between the eyes and the fixed object in the median line."

The angle formed when the object is placed at *R*, on

the median line, is expressed by R $= \frac{1}{R} = \frac{1}{1\,m.}$ or one unit of positive convergence ; then, if we place the object at one third metre from each eye, with binocular fixation, we have $\frac{1}{3}$ of $\frac{1}{1\,m.} =$ 3D or 3 metre angles. The nearest point of fixation with both eyes will give the greatest amount of convergence, or the *maximum* of convergence ; while the *minimum* of convergence, in normal cases, will be when the eyes are perfectly parallel, and represents zero ; because then the punctum remotum is situated at infinity.

This power of convergence is called the *positive* part, but we can have in normal eyes a divergence of the visual axes by the use of prisms placed before each eye, with their bases inward. This power of abduction of the visual lines will be represented as the *negative* part of the power of convergence. By referring to fig. 66 this, or negative part of the power of convergence, is shown by the dotted lines from *e* to *x*.

Now we require a certain amount of this positive power of convergence to perform near work with comfort and without the symptoms of asthenopia. This should be at least 3 metre angles more than the point at which the work is required to be placed. For instance, if a patient reads at $\frac{1}{3}$ of a metre, or 12 inches from the eyes, he will require 3 metre angles of convergence for that distance. But this is not sufficient ; he should have at least 3 m. a. more of the power of convergence in reserve to work comfortably at 12 inches. Consequently, we should have a reserve force twice as great as the power of convergence employed.

If we find, then, that the power of convergence is deficient, and that the patient is suffering from the effects of muscular asthenopia, how shall we treat them ? First, if of low degrees, as one metre angle, we may use prisms with their bases outward ; but we cannot use very strong ones, nor of more than 2° or 3° over each eye. If we have

a greater deficiency of convergence, we must resort to surgical means, of which we may use tenotomy of the external rectus. If this fail, we must advance the internal rectus or combine both operations, according to the desired result. But in every case, before proceeding to such extreme measures as a surgical operation affords, I would advise you to test the muscles very carefully several times, either by means of the prism test or that of the metre angle, as measured by Landolt's ophthalmodynamometer.

If we wish to order prisms for the relief of muscular asthenopia, we must test each muscle separately, and find the amount in degrees of insufficiency of the weakened muscle ; we must then divide this by 2, and the result should be equally apportioned between both eyes. Thus, if we find a weakness of the internal rectus of 8 degrees ; by dividing this by 2, and then placing one-half of the result over each eye, with the base of the prism over the weakened muscles, we will have a prism of 2° over each eye, with their bases placed inward, and the strain of convergence will be relieved. The visual lines will now be directed to a point removed from the eyes farther than the object is placed.

In very slight degrees of insufficiency you may obtain the effect of a very weak prism by having the glasses which correct the error of refraction decentred, *i. e.*, the centre of the glass placed either outward or inward, as needed, so that the patient must look through the outer portions of the glass. All spherical glasses are the same as prisms, with their bases or apices together ; then the periphery of a spherical glass must act as a prism.

As the rays of light proceed from the point A', and pass through a convex glass X, with the centre placed inward, or through a concave glass Y, with the centre placed outward, we will have the rays that would fall upon the retina at d bent inward to the macula m, and the eyes

will be directed toward the point *A*: in this manner we will relieve the strain upon the muscles of convergence. Consequently, to attain this object, in ordering glasses, you must decentre them, by placing the centre of the convex glass inward, and the centre of the concave glass outward.

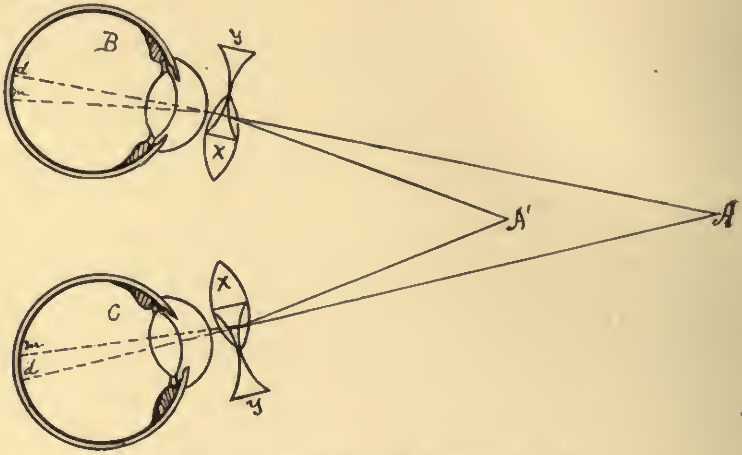


FIG. 67.—ACTION OF DECENTRED LENS.

The direction of the rays of light, with their conjugate foci, when passing through the periphery of a spherical lens, is shown in the following diagrams :

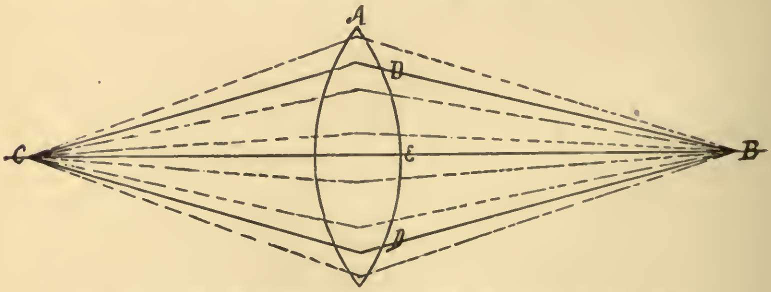


FIG. 68.—THE PERIPHERAL REFRACTION OF A BI-CONVEX LENS.

The above diagram represents a bi-convex lens, whose focal distance from the point *B* is at *C*; then all the rays from *B* must focus at *C*; and if we take those passing through the periphery, with the principal ones represented

by the lines *D*, *D*, we find that the rays which pass through the outer portion of the lens *A* are bent either outward or inward, according to the position of the lens to the median line of the body. The action of a concave lens is the same at the periphery, as shown by this diagram.

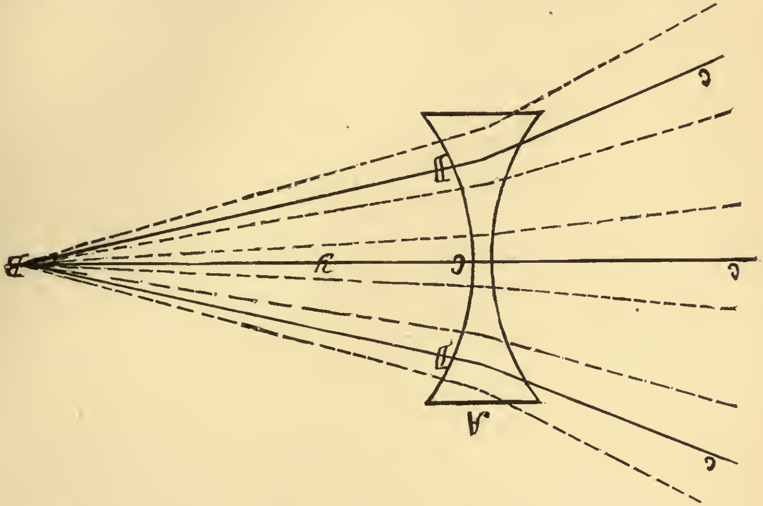


FIG. 69.—THE PERIPHERAL REFRACTION OF A BI-CONCAVE LENS.

We now have the direction of the rays passing through the periphery, shown by the lines *B D*, with their respective negative foci represented by the dotted lines. The lines in the two last diagrams will be the central ray of that portion of the convex or concave lenses.

You will find this method of decentring the glasses very useful in some cases, and it should, if possible, be preferred to that of adding prisms, as it will make the glasses so much lighter and thinner ; but it can only be used in cases where the weakness of the muscle is very slight.

EIGHTH LECTURE.

ASTIGMATISM.

History—First cases recorded—The triaxial ellipsoid—Division or varieties—Irregular astigmatism—Causes—Symptoms—Correction—Diagnosis—The keratoscope—Placido's method of diagnosis—Regular astigmatism—Refraction of a spherical and a cylindrical lens combined—The two focal points—" Interval of Sturm "—Position of retina—Astigmatism depends on curvature of the cornea—Simple hypermetropic—Simple myopic—Compound hypermetropic—Compound myopic—Mixed astigmatism—Direction of the two principal meridians—Direction of rays in simple—In compound—In mixed—Concealed—Landolt on—Method of testing for—Green's card test—Javel's card test—The stenopæic slit—Diagnosis with the ophthalmoscope.

GENTLEMEN :—We have been considering the eyeball in refraction, according to the length of the optic axis, finding, that it was too short in hypermetropia, and too long in myopia, while the chief refraction surface, the cornea, has been taken as a perfect surface of revolution, it being equal in all its different meridians, as far as its refractive power was concerned, and that all rays of light passing inward would come to a focus at some point on the visual axis. But we may have a different surface than that of the normal cornea, in which rays of light coming from infinity, and being parallel, will be refracted more or less in one meridian than the other according to the curvature of the cornea in each meridian.

This condition is called *astigmatism*, and generally has its seat in the curvature of the cornea, though it may exist in the surfaces of the lens. I think, if we consider that all cases of astigmatism are due to an unequal refraction of different meridians of the corneal surface, it

will assist us very much in the study of this interesting division of ametropia.

It is a curious fact that the first recorded case of astigmatism, that of Thomas Young, in 1801, was due to changes in the curvature of the lens, in speaking of which he says: "His eye in the state of relaxation collects to a focus on the retina those rays which diverge vertically from an object at the distance of ten inches from the cornea, and the rays which diverge horizontally from an object at seven inches distance." So that the rays in the vertical meridian must have been focused on the retina, just as in an eye that is myopic of one-tenth, and in the horizontal meridian myopic one-seventh.

The next case, that of Mr. Airy, reported in 1827, was also a case of compound myopic astigmatism, in which he proved that the cornea was not a perfect surface of revolution, but that the curvature was greater in the vertical meridian than in the horizontal, and that in both meridians it was more convex than in the normal or emmetropic eye. But it was not generally known until Donders completed his investigations, and gave us the correct views on the nature and the causes of astigmatism.

This condition generally exists in all normal eyes, but only to a very slight degree, less than $\frac{1}{40}$, and consequently does not disturb the vision sufficiently to call for any correction by glasses. When it becomes noticeably greater than that amount it will require proper consideration at your hands, though I would advise you to correct even the *smallest* degree of astigmatism if it causes any symptoms of asthenopia.

If we find that the curvature of the cornea is different in any two meridians, at right angles to each other, its surface will not present that of a perfect surface of revolution, but that of a *triaxial ellipsoid*, in which we find three distinct axes—first, of the central axis, on the visual

line; then of the vertical; and lastly, of the horizontal meridian. These two last axes may be shorter or longer than each other, according to the degree of refraction,—being longer than normal in a case of hypermetropia, and shorter than normal, with a corresponding greater curve, in myopia.

The word *astigmatism*, as applied to refraction, signifies that rays of light from a point are not reunited at a point; or that the rays in the different meridians will focus at different points on the visual axis as a line. We will first divide astigmatism into two forms, REGULAR and IRREGULAR. The last variety I shall consider very briefly, because it offers so few means for its relief.

In *irregular* astigmatism we may not only have a difference in the curvative of the meridians, but a difference in the curvature of a single meridian, generally caused by some disease of the cornea. This will leave its surface irregular in certain parts; as in the healing process of ulceration, the outer surface of the cornea has small facets which will materially interfere with the refraction of parallel rays of light in that meridian. We have it also in conical cornea, and in that condition of the crystalline lens in which the refraction of the various sections is different.

This condition of irregularity is very annoying to the individual, as he will see all objects in a blurred condition, distorted and irregular in all their parts. Our means for its relief are limited, as it is very obvious that this condition cannot be corrected by glasses. We must cut off all the peripheral rays, and allow the light to pass through only a small portion of the cornea. This can be done by means of an opaque diaphragm, with a small hole in the centre about 1 or 2 *mm.* in diameter, held close to the eye, in the position that will give the best vision, the aperture being placed over that portion of the cornea which has the most regular refraction,

You will readily see that, though by this means we shut off a large portion of the rays of light proceeding from an object and reduce the illumination, we at least gain the advantage of a perfect focus for those few rays which pass through the opening in the centre.

You will be surprised how much the sight of some of these individuals will be improved by this means. I can at present recall a case in my practice of a patient who was almost blind, unable to distinguish any object clearly, and yet with a small opening in a diaphragm of metal could readily distinguish the figures on the face of a small watch. This disc must be as close to the eye as possible, as the farther it is removed the smaller will be the field of vision.

A most interesting experiment, which will show you the difference of refraction in different parts of the meridians, even of the normal eye, is to hold the thumb and fore-finger between one eye and a light shaded with a white opaque globe. You will then notice that, as the fingers are brought nearer each other the outlines are very indistinct, and as they touch each other it will appear as if a small drop of a dark liquid lay between. Now place before the eye a card-board with a small pin-hole through it, and looking through this opening you will cut off all the rays of light that pass through the periphery of the cornea, the drop disappears, and the edges of the fingers are well defined. It is this curvature that causes the stars and other lights at night to have their radii, which would disappear if the curvature of a cornea were perfect.

The most ready means for the diagnosis of irregular astigmatism is that of the ophthalmoscope. By illumination of the eye at a distance of ten or twelve inches, you will notice that the reflex from the fundus is not clear in all its parts, but that certain portions of it will be cut off and appear as dark spots on the cornea. This is

caused by the return rays of light, as they are reflected from the retina, being refracted in such a direction that they cannot enter the eye of the observer. *Conical cornea* is well illustrated by this means, as it will appear as dark rings inside of the periphery of the cornea, changing their position and shape as the light is moved. In the examination of the fundus you will find that, although the eye can be illuminated, the vessels and disc will appear distorted and indistinct in certain parts.

Placido, of Porto, has devised a very interesting method

69*a*.—Placido's Keratoscope.

for the diagnosis of astigmatism, both regular and irregular, in which he uses a disc of card-board or zinc, about 23 centimetres in diameter, with a central aperture of about 1 centimetre; to which is attached a small tube about 3 centimetres long. On the opposite side is painted a series of concentric circles, alternately black and white. This instrument Placido calls the *keratoscope*. To use it, we place the patient with his back toward a window, and then with the disc reflect the light from a window to the eye to be examined, when we will see the image of those circles on the cornea by looking through the central aper-

ture. If the curvature of the cornea be normal, we will see the circles in their regular shape ; but if there be regular astigmatism the image will appear oval, with the longest diameter in the meridian nearest to the normal curve ; while if the cornea be the seat of irregular astigmatism, the image will appear very much distorted and some portions of the circles will not be seen.

In *regular* astigmatism we study the different meridians and their planes, each one separate from the other, but it will only be necessary for us to consider the two principal meridians. The intermediate ones have no focal points, consequently we can leave them out in all our calculations. Taking, then, these two principal meridians, with their planes, we shall find them always at *right angles* to each other and with their respective anterior and posterior focal points.

Before we enter on the study of these meridians and their planes, let us consider the action and direction of rays, as they pass through a refractive medium, the same as that of an astigmatic eye, and then we can better appreciate the refraction of astigmatism. To do this we require a convex spherical lens to represent the refraction of an emmetropic eye ; a convex cylindric lens to represent the astigmatism ; a point of light ; with a screen to represent the retina. Now, you will remember that the focal point of a spherical lens is round, and situated at its focal distance, according to the curvature of the surfaces ; also that the focal point of a cylindrical lens forms a line the same length as its diameter, and for parallel rays always found at the focal distance of its curved surface, parallel to the axis.

If we place these two lenses together, and pass the rays of light through them, you will find that we have two focal points, each represented by a short focal line. The first focal line is situated at the focal distance, which

is found by the addition of the focal power of the two lenses combined; and the second, at the focal distance of the spherical lens alone. These two focal lines will be found on the principal axis of the combined lenses. This can be easily shown by placing the screen at a suitable distance from the lenses, and your point of light at infinity. At all other points there will be no distinct images, but only an illuminated portion of different shapes, formed by the circles of diffusion, as the rays pass between or beyond the focal points. The interval or space between these two focal points, or focal lines, is called the "*interval of* STURM," and we will find the direction of the lines forming these two focal points,—one parallel with, the other at right angles to, the axis of the cylindrical glass.

Let us place a convex cylindric glass of $\frac{1}{10}$ focal distance over a convex spherical lens of $\frac{1}{10}$, with the axis vertical. Then all the rays that pass through the lenses, in the same plane as the axis of the cylindric lens, would be only focused by the spherical lens, at a point ten inches from the combined lenses; while all the rays that would pass in a plane at right angles to the axis would be refracted by the power of both lenses, and would form a distinct line at five inches from them.

But why do these focal points form lines by this combined system of lenses?

To explain this I must refer you to figs. 70 and 71. In the vertical plane we will represent the refraction of the rays as they pass through the combined lenses in a plane parallel with the axis of the cylindric glass. In this plane the cylindric lens does not bend the rays, which are only refracted by the spherical lens. But in the opposite meridian or plane, at right angles to this (see fig. 71), we have the rays refracted by both lenses, and the focus is at a much nearer point.

If we take the first focal distance or line in the two

planes at right angles to each other, which we find at *a* (fig. 71), then all the rays that pass in the horizontal plane will focus at the point *a* on the principal axis *oo*. But we find that the rays passing in the vertical plane, parallel with the axis of the cylindric glass, have not yet come to their focal point, and will fall upon the screen at the point *a* as a vertical line *cb* (fig. 70), whose length would be from *b* to *c*. As we now remove the screen from the lenses, all distinct focus is replaced by circles of diffusion. These form an ellipse, with the long axis ver-

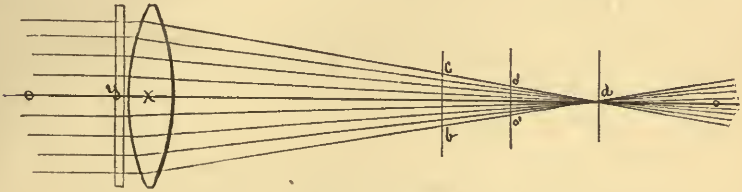


Fig. 70.—Vertical Plane, Compound Cylindric Lens.

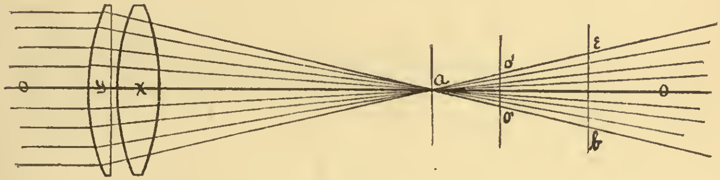


Fig. 71.—Horizontal Plane, Compound Cylindric Lens.

tical, until the screen is a little less than midway between the focal points, when the diffusion circles become round at *o′o′* and *o′o′* (both diagrams). Removing the screen still farther, we have the same blurred ellipse, but now with its long diameter horizontal, until we reach the second focal point, at *d* (fig. 70), when we have a distinct horizontal line. This is formed by the focus of the rays in the vertical plane, and drawn outward as a line by the diverging of the rays of light which have already focused at the point *a*, in the horizontal plane (see fig. 71), represented by the line *e* to *f*.

We have then two focal points, formed first by the rays of one plane being brought to a focus, and by the rays of the opposite plane before they have reached the focal point ; and second, the focal point of the vertical plane, and the divergent rays of the horizontal plane. You will notice that these lines are formed by the rays which are not in focus, and the edges of the lines by the rays which are in focus, as you trace the course of the rays to each focal point.

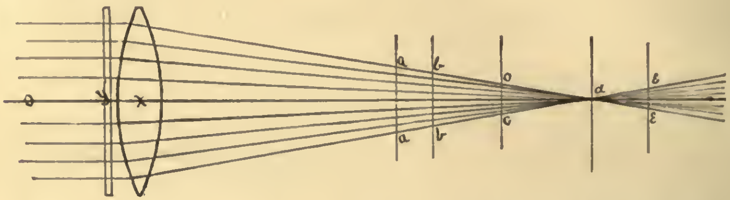


FIG. 72.—COMPOUND CYLINDRIC LENS, ILLUSTRATING ASTIGMATISM. (VERTICAL PLANE.)

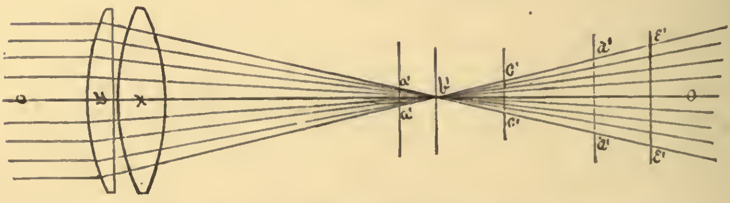


FIG. 73.—COMPOUND CYLINDRIC LENS, ILLUSTRATING ASTIGMATISM. (HORIZONTAL PLANE.)

If we now replace the combined lenses by the dioptric apparatus of the human eye, and the screen by the retina, you will see that different positions of the retina on the optic axis must influence the direction of the rays as they strike the retina, and there produce all the different forms of refraction. If we place the retina at the position of the line *aa* and *a'a'* (figs. 72 and 73) on the principal axis, the rays will fall upon it in both meridians or planes, the same as in the hypermetropic eye, before a focal point is reached, but more separated in one meridian than in the

other (compound hypermetropic astigmatism). At the position of the line *bb* and *b′* the focus of one meridian is at the focal point, *b′* (emmetropic); the other still hypermetropic, *bb* (simple hypermetropic astigmatism). At the position of the line *cc* and *c′c′* one meridian is still hypermetropic, *cc*; but the rays in the other have now met in front of the retina, and therefore at *c′c′* this meridian is myopic (mixed astigmatism). The retina is beyond the focal distance of the second meridian. At the position of the line *d* and *d′d′* the rays of the vertical meridian have now come to the focal point, *d* (emmetropic); but the horizontal meridian is still myopic, *d′d′* (simple myopic astigmatism); and then, if the retina be placed still farther away from the refractive apparatus, as in the position of the line *ee* and *e′e′*, the rays in both meridians will strike the retina after they have passed the focal points, and both meridians will be myopic, but more in one meridian than in the other (compound myopic astigmatism).

The distance between the two focal points, as from *a* to *d* (figs. 70 and 71), or *b′* to *d* (figs. 72 and 73), will represent the *focal interval of Sturm*, consisting of the various changes in the circles of diffusion, as the screen recedes from the anterior to the posterior focal plane.

Let us now apply these principles to the astigmatic eye and its different conditions of refraction.

We have stated that, as a rule, all cases of astigmatism depend upon the greater or less curvature of certain meridians of the corneal surface, different from that of the normal surface of revolution. As this curvature is greater or less, just so much will we have more or less refractive power in their respective meridians. We may have the curvature of one meridian normal; consequently the rays passing inward in that plane will focus upon the retina, while the meridian at right angles to it may be

more or less convex, so that the rays in this plane will be focused either before or behind the retina, according to the refractive power of the meridian of the cornea.

Astigmatism is divided into five varieties, according to the curvature of the two principal meridians of the cornea, as follows:

First—Simple hypermetropic astigmatism (Ah.), in which the curvature of one meridian is normal and the rays passing inward in that plane will focus upon the retina; while in the meridian at right angles to this the curvature is less than normal, and consequently the rays passing inward in this plane will focus behind the retina.

Second—Simple myopic astigmatism (Am.), in which the refraction in one meridian is normal, while that in the other is myopic, or will focus the rays in front of the retina.

Third—Compound hypermetropic astigmatism (H. with Ah.), in which both meridians are hypermetropic, but one more than the other; or the refraction of the eye is hypermetropic—*i. e.*, the optic axis is shortened, while the curvature of the cornea is the same as that in simple hypermetropic astigmatism.

Fourth—Compound myopic astigmatism (M. with Am.), in which both meridians are myopic, but one of a greater degree than the other; or the refraction of the eye is myopic—that is, the optic axis is too long, while the curvature of the cornea is the same as that in simple myopic astigmatism.

Fifth—Mixed astigmatism (Ahm., or Amh., according to the predominating degree of refraction), in which one meridian is hypermetropic, and the other myopic, at right angles to each other.

You will then understand that we only consider the two principal meridians and their refraction in each plane, calculating the refraction both with the test glasses,

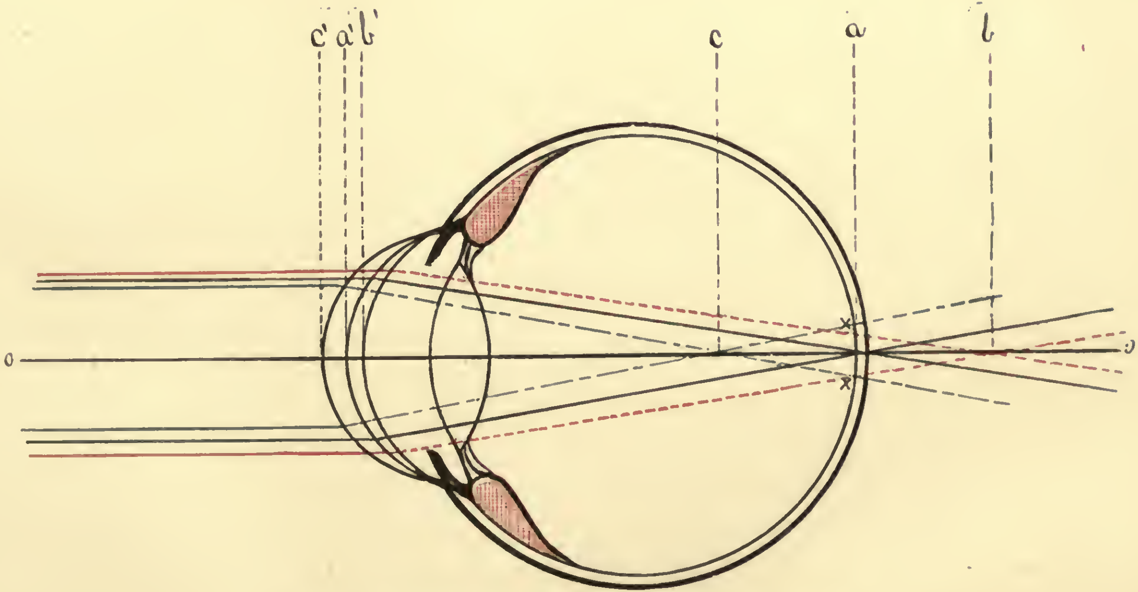


FIG. 74.—DIAGRAM ILLUSTRATING SIMPLE ASTIGMATISM.

retinoscopy and the ophthalmoscope, each one separately, and without regard to the refraction of the intermediate meridians.

Landolt gives us the following definition of astigmatism: "Regular astigmatism is that condition in which the refraction is different in the different meridians of the eye." This, then, will cause the cornea to have that form of a triaxial ellipsoid, with the two principal meridians generally vertical and horizontal, the greatest curve being in the vertical meridian; but the principal meridian may be inclined from the vertical, and occupy the position of any of the degrees of the arc of a circle from 0° to 180°. (See fig. 22.)

A peculiar fact connected with this is, that you will generally find the principal meridians to correspond in each eye, viz.: If one meridian, say of the right eye, incline toward the nose at an angle of 45° from the vertical, you will also have the corresponding-meridian of the other eye, the left, inclined toward the nose at an angle of 135°, being 45° degrees on the opposite side of the vertical. Also if one meridian incline toward the temple, the meridian of the other eye will incline that way. Finally, you may have some cases, in which one meridian will incline toward the nose and the other toward the temple, both being situated at the same degree.

Let us now follow the course of the rays of light as they pass through the dioptric media, in the two principal planes of the astigmatic eye, in each of the several varieties. First, we take the two principal meridians of the eye in simple hypermetropic and simple myopic astigmatism, as shown in the diagram facing page 155.

We will take the rays of one meridian, say the vertical, and represent the refraction and focus by the lines, while in the planes at right angles to that, we will represent the refraction and focus by the red dotted lines (- - - - -) in

hypermetropia, and by the green lines and dots (- — — - — -) in myopia.

Now the retina being situated at *a*, all the rays passing in the vertical plane, with the normal curve of the cornea *a′*, will focus on the retina at *a*. But in the case of hypermetropia, the curvature of the cornea, *b′*, in this meridian, being less than normal, the rays, as shown by the dotted lines, will focus behind the retina, at *b*, on the visual axis *oo*. They will strike upon the retina, at *x x*, before they have come to a focus, and will there form a line parallel with the hypermetropic meridian.

The same result takes place in the myopic meridian, as shown by the lines and dots; as,—the emmetropic meridian being shown by the lines.—The rays in the myopic plane, refracted by the increased curvature of the cornea at *c′*, will come to a focus at *c*, before they have reached the retina; there crossing at the focal point, on the visual axis *oo*, they will strike the retina in a divergent direction, at *x x*, and form a line in the same meridian as that of the increased curvature.

If we now pass to the compound forms of astigmatism, as shown in the diagram facing page 156, the position of the retina, *a″* is now changed: in hyperopia, being in front at *b″*, and in myopia, behind at *c″*. Consequently, if we represent the vertical meridian by the black lines, we will see that in the case of hypermetropia, with the retina at *b″*, the rays in a vertical meridian will focus behind the retina at *a*. The rays in the opposite or horizontal meridian—as shown by the red dotted line—will focus still farther at a point behind the retina, at *b*, so that the image upon the retina will be blurred in both meridians, the rays in the vertical plane being refracted by the normal curvature of the cornea *a′*, and the horizontal plane by the hyperopic curvature *b′*. Again, the same combination takes place in compound myopic astigmatism,—as shown by the green

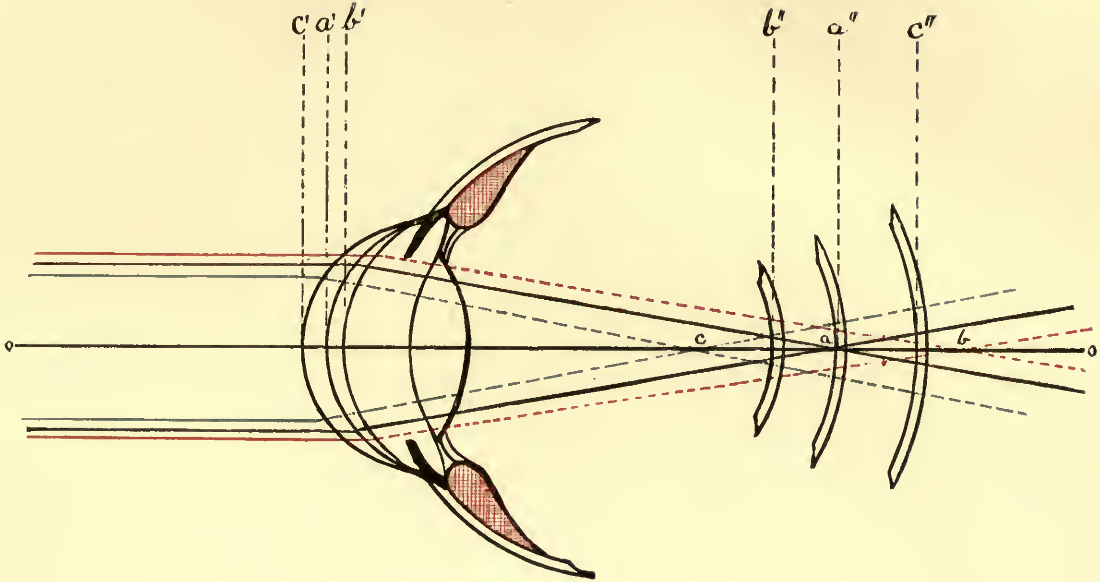


Fig. 75.—Diagram Illustrating Compound Astigmatism.

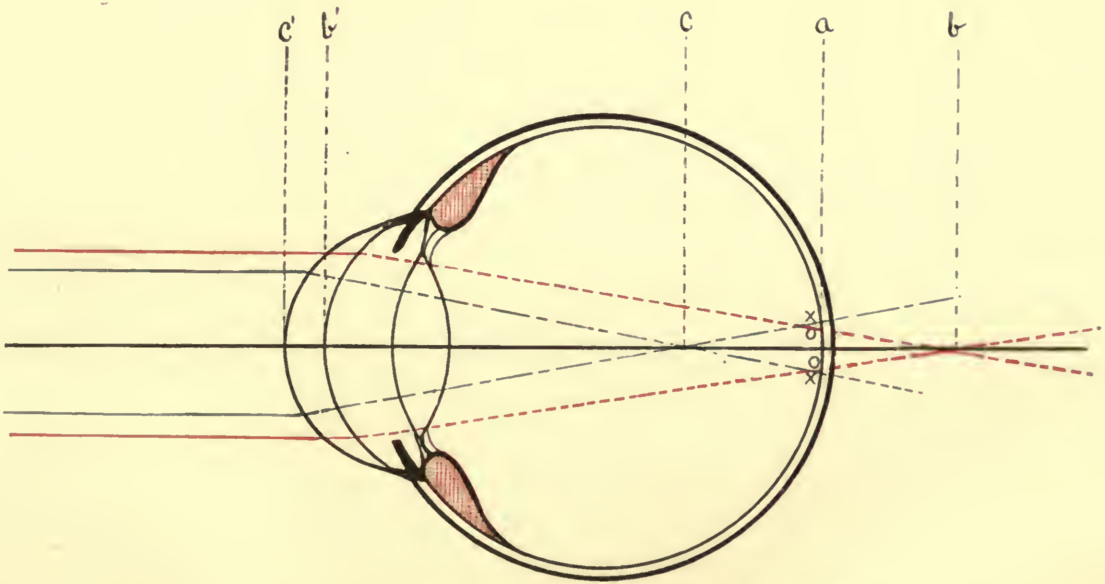


FIG. 76.—DIAGRAM ILLUSTRATING MIXED ASTIGMATISM.

lines and dots, in the horizontal meridian, and by the black lines in the vertical meridian. But in this case the retina is situated at c'', behind its normal position, the optic axis being elongated. Consequently the rays of light of the vertical and horizontal meridians will both focus at points in front of the retina and, crossing, will form blurred images,—one focal point being at c, and the other at a, both in front of the retina at c''; the rays in the vertical plane being refracted by the curvature of the cornea a', and those in the horizontal plane by the myopic curve at c'.

As we take the last variety in the diagram facing page 157, that of mixed astigmatism, we again find the retina at its normal position a, but owing to the curvature of the cornea the rays in both principal meridians or planes will not focus on the retina. In one meridian they will focus in front of the retina (myopic), and one behind the retina (hyperopic). If we illustrate the vertical, hyperopic meridian by the red dotted line, and the curve b' of the cornea, we find that the rays in this meridian will focus behind the retina. The horizontal, myopic meridian—shown by the green lines and dots, and the curve c' of the cornea—will focus in front of the retina at c. No distinct image can then be formed at the retinal plane, when the convergent rays o o, and the divergent rays x x, fall upon it, as one focal point will be at c, and the other at b. Now these several varieties of astigmatism must then depend upon two principal facts: first, the changes in the curvature of the cornea at certain meridians; second, the length of the optic axis affecting the focus of the rays in all meridians; and, last, that in mixed astigmatism we have a decided change from the normal curvature of the cornea in both principal meridians, making one myopic and the other hyperopic.

I think that this method of explaining the various forms of astigmatism is the most simple and easy to un-

derstand, leaving out of our consideration those rare cases in which the astigmatism is due to changes in the curvature of the lens surfaces. Their diagnosis is too complex for the scope of these lectures, while their correction by cylindric glasses is the same.

Let me caution you at this point that you may meet cases of astigmatism that will be *concealed* or caused by an irregular contraction of the ciliary muscle, thus changing the refraction of the lens in different meridians. This condition you will discover by the action of atropine, and by the ophthalmoscope. If concealed, the action of atropine on the ciliary muscle will cause the astigmatism to become apparent with the trial by glasses. Landolt, in his work on Refraction, page 322, calls this condition of unequal contraction of the ciliary muscles "*dynamic* astigmatism of the crystalline," and, where the lens causes the astigmatism when in a passive state, "*static* astigmatism of the crystalline." But, preceding that, Landolt says, on the same page: "In the vast majority of cases, fortunately, it suffices to know the total astigmatism of the eye, without our needing to concern ourselves with the question as to what part is due to the cornea and how much to the crystalline."

Let us now determine the amount or degree of astigmatism present in a given case, and consider the methods which we shall use for obtaining that result.

In all cases our first test must be with the trial glasses, using those which are spherical to correct any condition of hypermetropia or myopia that may be present, proceeding the same as we would in the examination of simple cases of ametropia without astigmatism. We then select the strongest glass that the patient will accept in hypermetropia, and the weakest glass in myopia. With these glasses properly selected, in astigmatism we find that the acuteness of vision does not correspond to the normal

vision of $\frac{20}{20}$; or that the patient will miscall certain letters on one line, while he may see similar letters on another line—as, for instance, he may see with a convex or concave glass, as the case may be, $\frac{20}{30}$ or perhaps $\frac{20}{20}$.

Now to commence our examination, we would select the strongest convex glass that will give the best vision at twenty feet. Then I prefer to take a convex glass about .05 D weaker than this, place it before the examined eye, and add to it a cylindric glass. First, with the axis at 180° or horizontal, and slowly rotating the axis from *right to left*, find the meridian at which the vision is improved. At this meridian place the strongest convex cylindric glass which will give the best vision for the letters placed at infinity or twenty feet. If this combination of a spherical and a cylindric glass cause the vision to equal $\frac{20}{20}$, we then have a case of compound hypermetropic astigmatism.

But if we find no improvement with the convex cylindric glass, we may then try a concave cylindric over a convex spherical, always commencing with a glass having the same refractive angle, only negative, as the convex spherical already placed before the eye. Placing this concave cylindric glass with its axis at 180°, turn the axis slowly to the left, and, if it give perfect vision ($\frac{20}{20}$) at any meridian, you will then have a case of simple hypermetropic astigmatism. You can prove this by removing both glasses and substituting a convex cylindric glass of the same refractive power. For instance, if your patient's vision be improved to $\frac{20}{20}$, with a convex spherical glass of 2 D, over which you have placed a concave cylindric glass of 2 D, with the axis at 90°, you will neutralize the refractive power of the spherical glass in the meridian of 180°, while it will remain of the same refractive power in the meridian parallel to the axis of the cylindric glass. Hence it would be the same as a simple convex cylindric

glass of 2 D, with the axis placed horizontal. To prove this try the convex cylindric glass alone, and see if you have the same vision.

Now, if we find that we require a stronger concave cylindric glass than the one just illustrated, then select the weakest which will give the best vision, and the trial by glasses gives us a case of mixed astigmatism. For instance, if we used a convex spherical glass of 2 D, and placed over that a concave cylindric glass of 3 D, with its axis vertical, or at 90°, the refraction of this combination would be obviously for the vertical meridian—the meridian parallel to the axis—still convex 2 D. In a horizontal meridian it would be (— 3 D) — (+ 2 D) = — 1 D. Consequently we would have a case of hyperopia of 2 D in the vertical meridian, and a myopia of 1 D in the horizontal.

Let us now test a case in which there is no improvement of the distant vision, or it is diminished with convex classes. We may then proceed to try the concave glasses, and we select the weakest concave spherical that will give the best vision. Then, if the vision be improved by adding a convex cylindric glass to the concave spherical already selected, of the same refractive power, but positive,—turning the axis from right to left until we reach the meridian of best vision,—we will have a case of simple myopic astigmatism. We may prove this by using the negative cylindric glass of the same refractive power, placing the axis at right angles to the position occupied by the convex cylindric glass used. For, if we have selected a concave spherical glass of 2 D, and over this have placed a convex cylindric class of 2 D, with the axis vertical, its refractive power will be the same as that of a concave cylindric glass of 2 D, with its axis placed horizontal.

Proceeding still further in our examination, if we find

no improvement with the convex cylindric glass, we will now proceed to try the addition of concave cylindric glasses to the concave spherical glass first selected, and turn the axis slowly to the left until we find the proper meridian. Then find the weakest concave cylindric glass that will give the best vision, and we have a case of compound myopic astigmatism.

I have found this method of testing the astigmatic eye the most reliable; and at the same time the most simple and rapid by which we can obtain the best results, particularly for clinical work. It is usually necessary in astigmatism that the accommodation of your patient be perfectly at rest. This condition you will only obtain in complete paralysis of the ciliary muscle by the use of some mydriatic, as atropine. This is the best and most reliable drug for this purpose, as your trial by glasses must then give you the true error of refraction. You should not use atropine in persons over fifty or sixty years of age, nor is it usually necessary at forty, as then the amplitude of accommodation being about *nil*, will not interfere with your tests, and the results will give the total error of refraction.

In reference to the calculations necessary as regards the refraction of the glasses when combinations are used, you will only calculate the refraction in the two principal meridians, one being always parallel to the axis of the cylindric glass, and the other at right angles to that meridian. Then remember in your result to always place the axis of the cylindric glass at right angles to the axis of the glass used in the combination.

This examination of the visual acuteness and the correction of astigmatism is undoubtedly the best and most reliable, particularly if the examined eye be under the influence of atropine. But we should also confirm the examination of the vision by the results obtained in ex-

amining each meridian with the stenopæic slit; the radiating lines placed at twenty feet; by the method of retinoscopy; and, lastly, by testing and estimating each meridian with the ophthalmoscope.

You will then proceed to test your patient with the figure representing radiating lines running in different directions from a common point on a white ground. They should be equidistant and exactly alike.

FIG. 77.—GREEN'S TEST-CARD FOR ASTIGMATISM.

Various designs have been devised for this purpose, as those of Javel, Green, and others. I prefer Green's card for this purpose, which represents the lines as the spokes of a wheel placed equidistant, and numbered as the hours on the dial of a clock, in which the lines running from XII to VI will be vertical, and those from IX to III will be horizontal, etc. Or you may use the lines which radiate like a fan (Javel's), beginning at the left end of the horizontal meridian and spreading out to the right. Then

the vertical lines will be at 90° and the horizontal lines will correspond to 180°.

You will then ask your patient which line he sees the best or most distinctly with the examined eye, and which line is most indistinct; but first correct any existing error of refraction with the spherical glass that will give the best vision. In this way you correct the hypermetropia or myopia. Then add the correcting cylindric glass at the proper angle; this will make all the lines on the astigmatic card appear alike, placing the axis of the cylin-

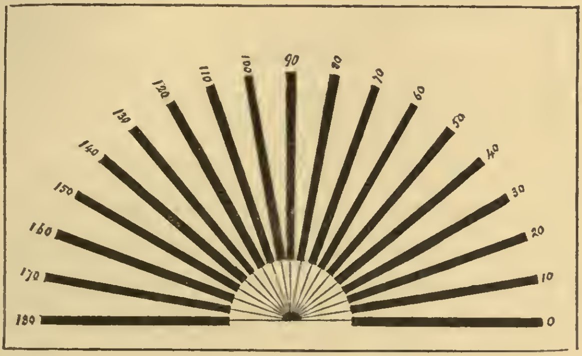


FIG. 78.—JAVEL'S TEST-CARD FOR ASTIGMATISM.

dric glass at right angles to the direction of the lines which are seen darkest and most distinctly. These lines are always seen in the meridian of greatest ametropia, provided the accommodation be at rest—that is, in the meridian of the cornea with the curve greater or less than normal.

You can remember this fact and the reasons for it, because if we find the curvature of the cornea greater in the vertical meridian, then all the rays that pass inward in that meridian will cross before they reach the retina; consequently, when they do strike the retina, each ray will overlap the other, while the rays which pass inward in the horizontal meridian, being emmetropic, will exactly focus upon the retina; and as these rays form the edges of the line

they are seen clearly and distinctly. I shall illustrate this to you more fully in the estimation of astigmatism with the ophthalmoscope.

The next method by which you may confirm the results of the two previous examinations is the test made with the *stenopæic slit*. This consists of a disc of metal, of the same diameter as the usual test glasses, with an opening or slit in the centre about 12 *mm.* long, having a slide attached so that the opening can be made of any desired width, the usual distance being about one *mm.* This will cut off all the peripheral rays in one meridian, but allows them to pass freely in the other.

Place the stenopæic slit before the examined eye, with the opening horizontal, and, turning it from right to left, find the position at which the patient has the best vision. If in this meridian you find $V = \frac{20}{20}$, then that meridian must be emmetropic, and the lines will be all alike. But if not, you will then add either a convex or a concave spherical glass until all the lines are equal and the best vision is obtained. Then test the meridian at right angles to this in the same way, adding either convex or concave glasses as may be necessary.

If you require a glass over the slit in each meridian, one stronger than the other, the weakest glass will give you the refraction of the least meridian, and the second glass that of the greater, while the difference between them will give you the amount of the astigmatism.

If the examined eye, with the stenopæic slit at 180°, has $V = \frac{20}{20}$, with $+\frac{1}{20}$, and at 90° $V = \frac{20}{20}$, with $+\frac{1}{10}$, then you have hypermetropia of $\frac{1}{20}$ in the horizontal and $\frac{1}{10}$ in the vertical, meridian. The proper glass for correction would be $+\frac{1}{20}$ s. $\bigcirc + \frac{1}{20}$ cyl. axis 180°, as this glass will have the correct refraction in both principal meridians.

As this stenopæic slit will cut off all the peripheral

rays in the meridian at right angles to its opening, then it measures the refraction in one meridian only, cutting off all the overlapping rays that would blur the edges of the letters. If the meridian be not emmetropic, you must then add a suitable glass that will make it so.

Let us now proceed to one of the final tests of astigmatism—the use of the ophthalmoscope, which I have fully explained in an article published in the *New York Medical Record*, vol. xxxix., No. 24, of June 12, 1886, p. 673, to the following portions of which I will call your attention :

"The diagnosis and determination of astigmatism with the ophthalmoscope by the direct method is not only exceedingly interesting but somewhat difficult, unless we estimate each of the two principal meridians separately. It, then, should become almost as easy as the diagnosis of simple hypermetropia or myopia, when we have simply an elongation or shortening of the optic axis.

"In determining the simple errors of refraction, we take as our standard of comparison the minute vessels of the disc or retina, or, better still, the delicate tapetum formed by the choroidal epithelium, and then, in hypermetropia, use the strongest convex glass behind the aperture of the ophthalmoscope with which this tapetum can still be distinctly seen. This will give the amount of hypermetropia; while in myopia we would select the weakest concave glass that will render the blurred tapetum distinct, and this glass will give us the amount of myopia.

"Now in astigmatism we cannot use this delicate test, so we select the edges of the optic-nerve entrance, which, passing in a circle, will give us short lines running in any direction ; or the minute delicate vessels that you will find in different parts of the retina or on and around the optic disc. The most delicate test is that of the brilliant white line running along the centre of each artery of

the retina. If we take any of these points for observation, and can decide which will focus upon the retina of the observer's eye, these vessels or lines will give us the direction of the meridian of greatest ametropia, provided in all cases that the accommodation of the observer be in a state of complete relaxation.

"We will precede the study of the errors of refraction caused by astigmatism, by the supposition that very few are able to have such complete control over their accommodation that they can at all times completely relax it, so that the observer's eye, when estimating refraction, shall be in a state of complete rest. Now this defect will make but slight difference in estimating myopia, as the observer's eye cannot accommodate for convergent rays, but in hypermetropia it must be taken into consideration, although the practical results should be the same. For instance, very few examiners who are accustomed to use the ophthalmoscope can so control the accommodation that they can examine the fundus of a hypermetropic eye of 1 or 2 D and find the details blurred and indistinct. But, making our diagnosis from the fact that we can still see these details clearly, by placing a convex glass behind the aperture, (and the strongest convex represents the amount of total hypermetropia) so we must calculate the amount of astigmatism present, if hypermetropic, and only the individual vessels as our guide.

"I shall not quote the writings of our many standard authors, as it has seemed to me that nearly all of them have dismissed this most important subject, and one that is so necessary to the ophthalmologist, with very few words. Even our most illustrious master on refraction, Donders, says almost nothing, while Dr. E. G. Loring, in his excellent work, lately issued, on Ophthalmoscopy, devotes hardly five pages to this subject, though his explanations are unquestionably the best and clearest which it has been my pleasure to read.

"If we could so control the accommodation that, when using the ophthalmoscope, our eyes would be in a state of complete rest, as when under the influence of a strong solution of atropine, then I can understand and appreciate the teachings upon this subject. But if we consider that, with a large majority of those who use the ophthalmoscope, the accommodation is particularly *active* when examining a hypermetropic eye, we must study and calculate the errors of astigmatism in a somewhat different manner.

"In teaching the determination of astigmatism, we must only consider those rays of light that are reflected by the retina of the observed eye after proper illumination with the ophthalmoscope. In doing so, we must estimate separately the refraction of the two principal meridians, at right angles to each other; the direction in which the rays of light of each meridian leave the cornea; and the direction that they will have when they strike the retina of the observer's eye, after they have passed through the dioptric media of both eyes.

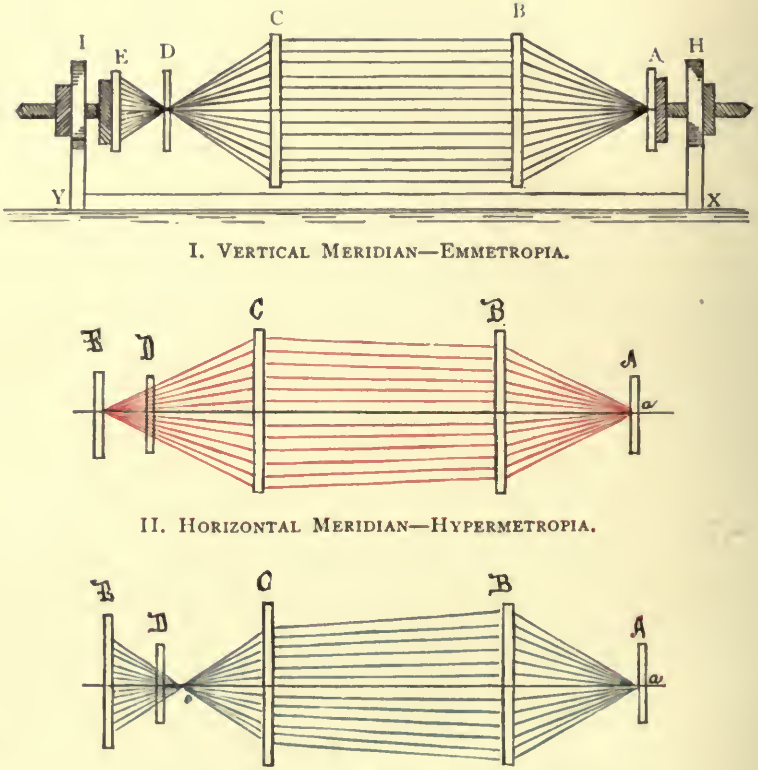
"This has been beautifully shown by my friend and assistant, Dr. W. H. Fox, at our clinics, and at his lectures at the Post-Graduate Medical School. This method, first used, I believe, by Professor H. Knapp, and as we have used it, consists of small discs of card-board to represent the refractive apparatus of the observed and the observer's eye, while small threads of different colors, placed in different planes, represent the rays of light in the two principal meridians.

"By this method, if we take the rays of light from any luminous spot in the retina, passing through the dioptric media of the observed eye, and then through that of the observer, their directions and focal points will be the same as parallel rays of light passing through a spherical and cylindric lens combined, so that we shall find beyond the refractive media of the observer's eye, pro-

vided it is emmetropic, the two principal focal points, with the *focal interval of* STURM between them; that in hypermetropic astigmatism the retina of the observer's eye lies at the anterior focal point, and that in myopic astigmatism the retina of the observer's eye lies at the posterior focal point and, further, that in compound astigmatism the retina is in front of the anterior focal point in hypermetropia and is beyond the posterior focal point in myopia, while in mixed astigmatism the retina lies between the anterior and the posterior focal point.

"Now, in all these cases, but particularly in that of simple astigmatism, which I shall take as a standard, we will find that the image, as formed upon the retina of the observer's eye, is elongated in the meridian of greatest ametropia, consequently all vessels or lines that pass in the direction of this meridian will be clearly seen, provided the accommodation be at rest, because the rays which define the edges of these vessels will pass outward through the emmetropic meridian, and will leave the eye as parallel, while all the rays that pass outward in the meridian of ametropia, when they strike the retina of the observer's eye, will simply overlap, so forming a clear elongated image. But in hypermetropic astigmatism the student will almost invariably use his accommodation, and now he will see the vessels in the emmetropic meridian. The rays will focus upon his retina at the posterior focal point exactly at right angles to the vessels parallel to the meridian of ametropia, and the rays in the hypermetropic meridian will now define the edges of the vessels.

"By looking at the drawings you will see in fig. i. the stand represented, with one set of card-boards and threads in position, showing the direction of rays of light in the vertical meridian, while in figs. ii. and iii. the card-boards and threads only are represented, but are so made that they can be easily attached to the stand by a slot,



I. Vertical Meridian—Emmetropia.

II. Horizontal Meridian—Hypermetropia.

III. Horizontal Meridian—Myopia.

Fig. 79.—Diagrams of Vertical and Horizontal Planes in Astigmatism.

and then tightened up by the nuts on the screws at the ends. These figures are reduced about one-sixth the actual size, and this method can be used to illustrate all varieties of refractions and astigmatism.

"Explanation: In fig. i. *X*, *Y* represent the stand, with two uprights, *H* and *I*, on each end, through which the screws pass, with a small movable nut on each screw, and by which the threads are tightened after the card-boards are in position. Then the card-board at *A* will represent the retina of the observed eye, and *a* the luminous point, *B* the refractive apparatus, while *C* will represent the refractive apparatus of the observer's eye, *D* the position of his retina, and *E* the position of the posterior focal point in simple hypermetropic astigmatism. By placing these card-boards in the stand, with the rays of the two principal meridians shown by different colored thread, they can be turned to any meridian in the arc of a circle, though in the drawing they are shown only in the vertical and horizontal. Then if you combine figs. i. and ii., or figs. i. and iii., you will see that in no case can the rays from the luminous point *a* form a point upon the retina of the observer's eye, but must be elongated in the direction of curvature different from that of emmetropia.

"In fig. iii., representing the horizontal meridian of an astigmatic eye whose refraction is myopic, we find the rays of light in this meridian or plane to pass outward convergent, consequently they will cross before they strike the retina of the observer's eye at *D*, and there form an elongated image. The rays passing outward in the other principal meridian will be parallel, as shown in fig. i. They will exactly focus upon the retina at *D*, and as these rays in this meridian form the boundary lines of the vessels in the opposite meridian, then, in this case, the vessels which pass horizontally will be clearly seen. This being the meridian of greatest ametropia, the axis of the

correcting cylindric glass must be placed at *right angles* to it, or, in other words, at right angles to the vessels which are distinct.

"If we now study the direction of the rays passing from a hypermetropic eye, under the same conditions, we shall find that they also form an elongated image upon the observer's retina in the same meridian of ametropia; but now the image is formed by the rays in the horizontal meridian reaching the retina at *D* before they have come to a focus, as shown in fig. ii., while the rays passing in the vertical plane, fig. i., are parallel and exactly focus upon the retina of the observer's eye.

"Now, if the observer is able to keep his accommodation completely relaxed, this proposition is *correct*, and he can only see the vessels that pass in the horizontal direction. But as so few of us, particularly those who are learning to estimate refraction, can keep the accommodation *at rest* when *divergent* rays pass in the eye, hence, using the accommodation, we will focus all the rays upon the retina, and all the vessels become clear. If we then place a convex glass behind the aperture of the ophthalmoscope, which takes the place of and relieves the accommodation, we now change the rays of light as if they came from an eye with simple myopic astigmatism. The convex glass will focus the divergent rays in the horizontal meridian upon the retina; at the same time they will bend the parallel rays in the vertical meridian, which will then focus before they reach the retina of the observer's eye. The position of the retina is now changed to the posterior focal point, and the vertical vessels can be seen most distinct exactly at right angles to the vessels seen with the accommodation relaxed. The emmetropic meridian is made myopic by the action of the convex glass, consequently the axis of the correcting cylindric glass must be placed *parallel* to the vessels most distinctly seen in hyperme-

tropic astigmatism when the accommodation or a convex glass is used. The strongest convex glass by which these vessels are made clear will represent the amount of ametropia.

"These same rules will apply in compound astigmatism, but we must first correct the general refraction in myopia by the weakest concave glass that will make the vessel in any one meridian distinct, and in hypermetropia by the strongest convex glass that will first *blur* the vessels in any meridian.

"We can illustrate these rules by the following cases: In simple myopic astigmatism the vertical vessels are distinctly seen through the aperture of the ophthalmoscope, then with — 2 D all the vessels are clearly seen, as the accommodation will correct the divergence of the parallel rays caused by the concave glass, hence the correcting cylindric glass would be — 2 D; cyl. axis 180°, or horizontal.

"In simple hypermetropic astigmatism all the vessels can be seen in every meridian, but if we place a convex glass, as + 2 D, the vertical vessels can still be distinctly seen, while all the horizontal vessels are blurred. We now find that the correcting cylindric glass will be + 2 D; cyl. axis 90°, or vertical, the axis now being parallel to the vessels most distinctly seen.

"Let us now take a case of compound myopic astigmatism. All the vessels will appear blurred, and the weakest concave glass which will make the vessels in any meridian clear, say — 2 D, will show the vertical vessels. Then we have general myopia of — 2 D, and the axis of the astigmatic glass must be at *right angles* to these vessels. We then measure the amount of the astigmatism by the weakest glass that will make all the vessels clear, as — 4 D, and the difference between these two glasses will give the amount of astigmatism. Thus the proper

glass to correct this case would be — 2 D $\bigcirc$ — 2 D cyl. axis 180°, or horizontal.

"But in a case of compound hypermetropic astigmatism all the vessels can be clearly seen, if not of too high a degree of hyperopia, as the accommodation will be active, and the strongest convex glass that will first blur the vessels in any meridian,—as with + 2 D the vessels in the horizontal meridian begin to blur,—this glass will represent the amount of general hypermetropia. Now, the axis of the astigmatic glass must be *parallel* with the vessels which are *still* distinctly seen; and as the strongest convex glass with which these vessels in the vertical meridian can be seen, as + 4 D less the amount of general hypermetropia, will represent the astigmatism, therefore the correcting glass would be + 2 D $\bigcirc$ + 2 D cyl. axis 90°, or vertical.

"In mixed astigmatism with the vertical meridian myopic and the horizontal meridian hypermetropic, you will see the disc elongated in the direction of the myopia, or vertically. All the vessels running vertically are distinct,—unless the accommodation is relaxed, when the vessels and all the details of the fundus will be indistinct. But this condition is difficult to accomplish, and so, using the accommodation, we can see the vertical vessels clearly; then the strongest convex glass through which they can be seen, as + 2 D, will represent the amount of hypermetropic astigmatism. Now place the axis of the correcting glass parallel to these vessels, and we have + 2 D, cyl. axis vertical; the hypermetropic astigmatism being in the horizontal meridian. Let us now place the weakest concave glass behind the aperture that will render all the details of the fundus clear, as — 2 D, and we have the amount of myopia. Placing the axis of the cylindric glass at right angles to the vessels first clearly seen, then the correcting concave cylindric glass will be — 2 D, cyl. axis 180°, or horizontal, with the myopic astigmatism in the vertical

meridian. So this case of mixed astigmatism will be corrected by + 2 D cyl. axis 90° ⊃ — 2 D cyl. axis 180°.

"I wish the student to remember that these calculations are only made in this way because most physicians who use the ophthalmoscope are unable to control the action of the accommodation ; while even if we do have perfect control at all times, then we can only see the vessels distinctly that are parallel to the meridian of greatest ametropia, and consequently the axis of the correcting cylindric glass must be at right angles to that meridian.

"I have been led to these conclusions from actual experience in the examination of a large number of cases of astigmatism without the use of atropine, and have confirmed the diagnosis afterward with atropine and the trial by glasses. Again, so little is written on this interesting subject, while I could give so many examples from my records, when on service at the *Manhattan Eye and Ear Hospital*, that have been studied and the diagnosis made by this method. At the same time, I know from personal experience that it is very difficult to so master my own accommodation as to obtain the results given in our text-books. Nor can I speak too highly of the ability to make a correct diagnosis of all the errors of astigmatism, as in many cases it will enable us to decide if it is necessary to continue the examination under the use of atropia ; and it shows us as well the cause of the apparent amblyopia.

"I would therefore conclude :

"That the direction of the axis of the correcting cylindric glass in myopic astigmatism is at right angles to the vessels which are most distinctly seen without a concave glass.

"That the direction of the axis of the correcting cylindric glass in hypermetropic astigmatism is parallel to the vessels which are most distinctly seen with a convex glass.

"That these same rules are applicable in compound astigmatism, only we must correct the general error of refraction first, and then the astigmatism.

"Lastly, that these rules are presented from the fact, as I believe, that the largest number of those who use the ophthalmoscope cannot control their accommodation at all times, when divergent rays of light enter the observer's eye."

In conclusion, let me urge you to examine all your cases carefully with the three tests I have given you: that of the test letters first; then retinoscopy; and, lastly, the ophthalmoscope. If you find they all agree, you may be satisfied in the result of your examination, and proceed to order the glasses accordingly. But if these three excellent tests do not agree, then you are justified in urging the use of atropine. You may then make your final tests, in the same way, that will in all probability be correct, and you will relieve your patients of their asthenopia and discomfort caused by their error of refraction due to astigmatism.

NINTH LECTURE.

RETINOSCOPY.

Retinoscopy or pupilloscopy—The theory of the concave mirror—The theory of the plane mirror—Direction of the rays in hypermetropia—In myopia—Diagnosis of refraction with the plane mirror—In hyperopia—In myopia—In astigmatism—At different meridians—Advantages—Caution in regard to—Its practical use.

GENTLEMEN :—The next method for the examination of the refraction and confirming the results of our previous tests, is that of *pupilloscopy*, or the *shadow test* as it is called. Dr. PARENT, of Paris, uses the name of *retinoscopy;* a term that, I think, is probably correct, as I shall try to show you that the phenomenon which is seen by this test arises from the illumination of the retina and not from any participation of the pupillary space or the shadow of the iris. That the iris does throw a shadow upon the illuminated portion of the retina I have no doubt, but only when the illuminated portion passes over the retina, beyond the line of sight; consequently the shadow of the iris cannot be seen by the examiner.

The first mention of this test in refraction is in DONDERS, (p. 490, edition 1864), whose attention was called to it by his friend *Bowman*, but no special use was made of the method at that time. Afterward Dr. Cuiguet, of Lille, demonstrated its value in the diagnosis of all the errors of refraction and astigmatism. In his investigations he used a concave mirror, and, although the final results may be the same, I would advise you to learn this method of diagnosis by means of the *plane mirror*, as you will find it much more easily understood.

In the use of the concave mirror, such as you have on your ophthalmoscope, or of one of greater diameter made for this purpose, you must remember that, being concave, the position of your illumination lies in front of the mirror at its focal point. From this point the rays enter the examined eye in a divergent direction. Then, as you examine an eye by this method, the light proceeding from an inverted image of the flame in front of your mirror, as the mirror is turned on its vertical axis to the right or left, the position of the flame will move in the same direction. As these rays of light reach the retina, moving on the nodal point as a centre, the illuminated portion of the retina will move in the opposite direction.

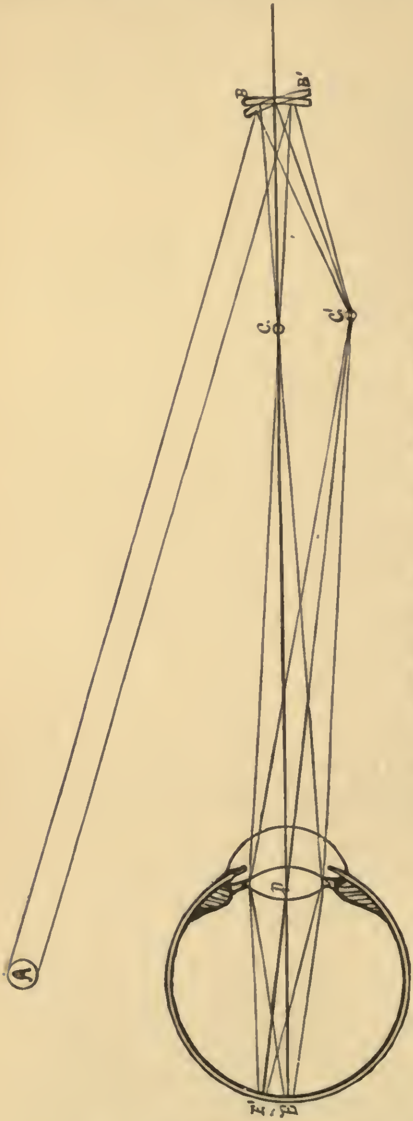


Fig. 80.—Retinoscopy with the Concave Mirror.

Let me illustrate this to you by the diagram in the horizontal plane:

The rays of light from the lamp at *A* will fall upon the concave mirror *B*, coming to a focus at the point *C;* they will then diverge and, passing through the dioptric media, will illuminate the retina at *E*. Now, if we turn the

mirror on its vertical axis to the left at B^1, the point of illumination will also move to the left at C^1, and the axial rays, turning upon the nodal point at D, will cause the illuminated portion of the retina to move to the right, at E^1; consequently, with a concave mirror, the illuminated portion of the retina will move in the direction opposite to that in which the mirror is turned.

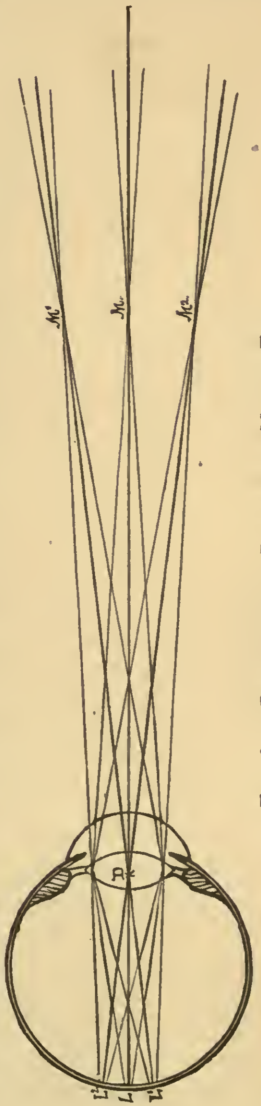


Fig. 81.—Retinoscopy: Rays from Myopic Eye.

Now in the use of this means of diagnosis, we must depend upon the rays proceeding from the retina, as they are reflected back toward the examiner; then, if the refraction of the dioptric media be emmetropic, the reflected rays, as they proceed from the examined eye, will be parallel, and the reflex will not have any decided movement, but with a slight tendency to move in the opposite direction to which the mirror is turned. In hypermetropia, the reflex will move in the opposite direction; but, if we have those movements of the reflex in the same direction in which the mirror is moved, unless of very slight degree, we must have myopia.

You will see by this diagram (fig. 81) that, as the rays proceed from the illuminated portion of the retina at L, they will emerge from the eye convergent, as they come from a point beyond the refraction of the dioptric system. We have a real image of the reflex, seen in

front of the observer, at the focal distance of the myopia at *M*.

Then, if the illuminated portion moves to L^1 or L^2 the real image will move to the right or left, as the case may be; or, as the mirror is turned, we now see the movement as an aërial image at M^1 or M^2 respectively. As the reflex from L^1 will be seen at M^1 and the reflex from L^2 will be seen at M^2, so, as the mirror moves to the left, the reflex also seems to move to the left, and when the mirror turns to the right so also does the image seem to move.

As I have stated to you, these movements, either with or against the movements of the mirror, may show very slight myopia, (less than $\frac{1}{40}$) emmetropia, or hyperopia. But if you place a convex spherical glass before the examined eye, so as to render the refraction still more myopic, by converging the emergent rays, and the reflex still moves in the same direction, you may be positive of myopia. But if you find that the reflex moves in the opposite direction to which the mirror is turned, with the weak spherical glass before the eye, you will have hypermetropia; as now the rays from the retina proceed as if coming from a point inside of the focal distance of the dioptric media, with the emergent rays divergent. The reflex will appear as a virtual image coming from the negative focal point of the dioptric media.

Having told you that the use of the plane mirror was the easier to understand, I will explain the method of using it and the theory upon which I think the movements of the reflex are based. By the use of the plane mirror you will find that all the movements of the illuminated portion of the retina are reversed. The rays from your point of illumination, though coming from the lamp at the side of or above your patient, will proceed as if they came from a point behind the mirror equal to the distance of the lamp from the mirror. If you are seated

40 inches from the examined eye and lamp, then the reflected rays from the mirror will enter the examined eye as if they came from a point 80 inches from it and will be almost parallel.

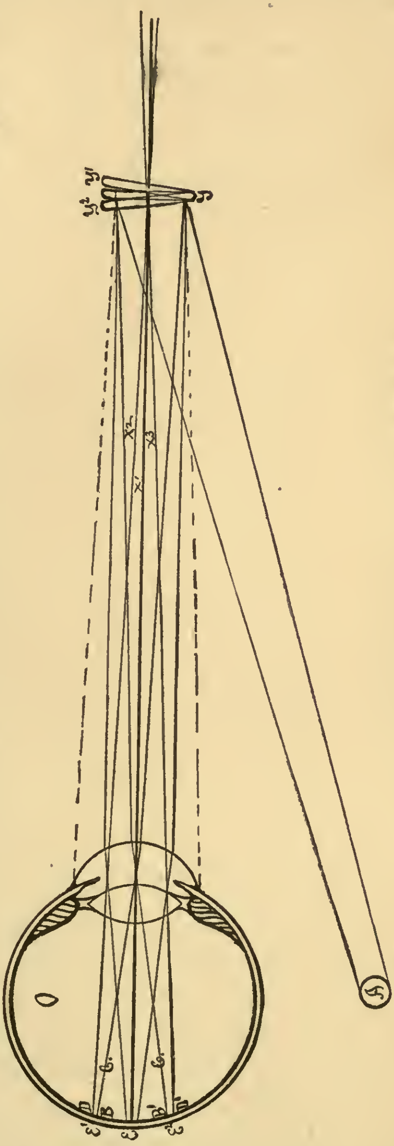


Fig. 82.—Retinoscopy with the Plane Mirror.

Then as these parallel rays come from this distant point, and as the mirror is turned to the right, the point of illumination will move to the left, or when to the left the light moves to the right and will not turn upon the nodal point of the examined eye, but will pass inward and illuminate the retina. This illuminated portion will move on the retina in the same direction as the mirror is turned, without regard to the condition of the refraction of the examined eye. You will now make your diagnosis of the refraction by the emergent rays, which, you will see, are influenced by the refraction of the dioptric media, as it may be emmetropic, myopic, or hypermetropic.

Let us examine this diagram, which will show you the direction of the rays in the horizontal plane ; at the same time you must remember that, if there be no astigmatism,

the rays will be the same in all meridians or planes of the eye. Now you have the plane mirror placed at the point Y, reflecting the rays of light from the lamp at A, as if they came from a point behind the mirror equal to the distance of the lamp from the mirror. This will illuminate the examined eye with a bundle or *cylinder* of light, composed of parallel rays around the axial ray X^1, starting from a point behind the mirror and passing through the dioptric media, they will illuminate the retina at E. If you now turn the mirror on its vertical axis to the right Y^1, the cylinder of reflected rays from the mirror will also move to the right and the axial ray will be at X^2, with the retina illuminated at E^1; and when the mirror is turned to the left Y^2, with the axial ray at X^3, we have the retina illuminated at E^2. Thus with the plane mirror we find that the illuminated portion of the retina moves in the same direction as the mirror is turned. In emmetropia, as the rays will pass outward from the eye in the same direction as they entered, there will be very slight, if any, movements of the reflex, as they come from a point on the retina equal to the focal distance of the dioptric media; but the reflex will appear very bright, with almost no movement or so-called shadow.

Let us now study the appearance of the reflex in cases of ametropia of more than $\frac{1}{40}$, in which the so-called *shadow* appears, and from which this test takes its name. It was supposed that the dark portion which appears in the pupillary space following the illuminated portion, as moved in different directions, was due to the shadow of the iris falling upon the retina, as the iris would cut off the rays of light. But I think we can prove that it is due to a different cause, and that the name *shadow test* is not the correct one, as has been stated in the text-books of ophthalmology.

In support of this theory, and to demonstrate to you what does cause this so-called shadow, let us again look at

fig. 82, and we shall find, taking the light from *A* and striking upon the mirror *Y*, a cylinder or bundle of rays projected against the examined eye *O*, with its axial ray shown by the line X^1. This being refracted by the dioptric media, we find the retina illuminated at *E*. When this axial ray corresponds with the optic axis, we find the pupillary space simply illuminated ; the return rays, in this case, being slightly divergent, and following almost the same path as they entered the eye *O*. If we now turn the mirror to the right, with the cylinder of light turning in that direction, we illuminate the retina at E^1. The right side of the cylinder, being cut off by the iris, forms a shadow of the latter on the retina at *D;* consequently cannot be seen by the examiner's eye placed behind the mirror. The same fact is shown in the diagram with the cylinder of light turned to the left, and the retina illuminated at E^2, with the shadow of the iris at D^1 behind the pupillary space.

We can now leave out the shadow of the iris and inquire : What does cause this " shadowy edge of the circles of diffusion that appear to pass across the pupillary space" ?

As our cylinder of rays passes to the right (fig. 82), following the axis X^2, and as the edges of this cylinder of light uncover the pupillary space to the left, the *dark portion* of the retina at *B*, *not illuminated*, will appear to the *left* of the pupil, *following* the illuminated portion of the retina as it passes to the right. It *appears as a dark shadow* coming from behind the iris, and passing in the same direction as the mirror is turned. In the examined eye, if hypermetropic, as these rays of light are refracted by the dioptric apparatus, and are again reflected by the retina, the return rays, being only slightly divergent, pass outward in almost the same path in which they entered. They will not interfere with the view of the dark

parts of the retina, so that we can readily appreciate the movements of the illuminated portion, formed of circles of diffusion by the lamp at *A*. When the mirror is turned to the left, the shadow of the iris is at *D*ʹ, and the non-illuminated portion of the retina at *B*ʹ appears as the shadowy edge.

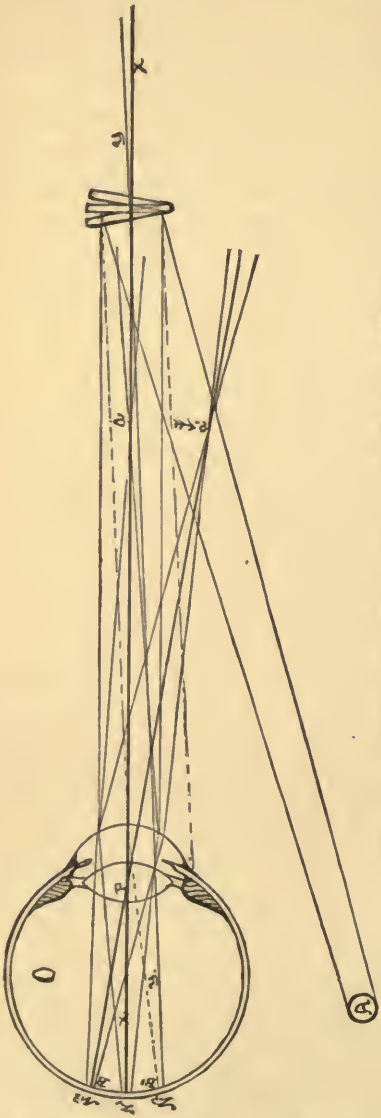


FIG. 83.—RETINOSCOPY WITH THE PLANE MIRROR: MYOPIA.

From the above description of the appearance of the retina in the hypermetropic eye, the position of the source of the illumination lies behind the mirror; and as the mirror is turned upon the vertical or the horizontal axis, the axial ray does not pass through the nodal point of the examined eye; as is the case when you use the concave mirror, where the source of illumination is in front of the mirror, and moves in the direction in which it is moved. Therefore, with the rays divergent as they enter the eye, the axial ray must turn on the nodal point, and we have the circles of diffusion on the retina moving in an opposite direction.

In myopia we find the retina illuminated by the same

cylinder of rays from the mirror, moving on the retina as the mirror is turned—though they illuminate the retina after they have passed the focal point,—with the axial ray at X or Y. As the rays from the mirror illuminate the retina at N^1, the return rays now passing through a refractive system whose focal point is beyond that of the dioptric apparatus, the emergent rays are convergent, and the real image of the circles of diffusion will be seen at a, appearing to light up the entire pupillary space. Let us now turn the mirror to the right, and we have the retina illuminated at N^3, but, the emergent rays having a positive focus at a, the axial ray will turn on the nodal point at P, and the real image, at a, must move to the left, as at a^1, and we see the dark portion of the retina at B forming the shadow. It appears to follow the inverted image a, to a^1, and is seen by the examiner *as soon as* the image of the circles of diffusion at a shall have passed the area of the pupil on the right side, and follows it, as it moves to the left, in a direction opposite to that in which the mirror is turned. This is an inverted aërial image of the illuminated portions of the fundus. The axial ray, Y, Y, shows the cylinder of light when moved to the left, with the retina illuminated at N^2, and as the aërial image moves to the right, the shadowy edge formed by the non-illuminated part of the retina at B^1 will follow it.

I shall endeavor to explain to you, as we take up each subject, that, in hypermetropia, with the plane mirror, the retinal reflex follows the movement of the cylinder of light, and appears to be followed by the dark portions or non-illuminated parts of the retina ; and that in myopia, having a real image of the retinal reflex, at the focal point of the dioptric apparatus, formed by the emergent rays, the image must pass to the right as the mirror is turned to the left : in other words, the retinal image moves in an opposite direction.

In using this test to decide your errors of refraction, some oculists advise that you should so place the examined eye that the optic disc will be directly behind the pupillary space. I do not think that this is necessary, nor exactly correct, as the refraction of the eye may be different at the region of the macula than at the nerve entrance, as cases have been recorded. So I would advise you to test your cases as near the macula as possible, by having your patient look a little to one side or above your eye. If you can dilate the pupil and stop the action of the accommodation by the use of atropine, your examination will be much more correct; though the accommodation has very little influence on the result if you examine your case in a dark room. You will then have a very satisfactory test, even in cases of hypermetropia with spasm of the accommodation. I would also advise you to correct any error of your own refraction by proper glasses.

With these precautions, what will be the result of your examination in cases of ametropia, where the optic axis is either too long or too short, as in myopia or hypermetropia? We shall find first that, if the position of the retina be not at the focal point of the dioptric media, the rays of light, as they illuminate the examined eye, will fall upon the retina before they have come to a focus, as in hypermetropia, or after they have passed the focal point, as in myopia, and the illuminated portions of the retina will be a round spot, with indistinct edges, formed by the circles of diffusion.

You can use this fact as one of your means of diagnosis, as the degree of luminosity of the reflex will show the degree of ametropia. The greater the luminosity, the nearer the refraction of the examined eye will be to that of emmetropia. This is well shown in the higher degrees of hypermetropia and myopia, where the emerging rays are either very divergent or very convergent, and consequently

an insufficiency of rays to enter the examiner's eye, to enable him to appreciate the movements of the reflex.

This degree of brightness in the reflex, due to the refraction, is caused by the fact that, when the retina of an emmetropic eye is illuminated by the mirror, the entering rays form a clear, bright image on the retina ; while in ametropia, as I have just stated, the reflex is formed, not by a clear image of the flame, but by the circles of diffusion on the retina caused by the ametropia.

In the hypermetropic eye, as they reach the retina in front of the focal point, the rays from a plane mirror will form a round spot, moving in the same direction as the mirror, and moves as it rotates to the right, the shadow of the iris on that side, will cut off a portion of the illuminated space, but cannot be seen by the examiner. Now, as the reflex passes to the right, the portion of the retina not illuminated comes behind the pupillary space, and we have the dark appearance,—simply a portion of the pupillary space. This seems to come from behind the iris, opposite to the side toward which you are moving the cylinder of light, by turning the mirror, and moves in the same direction.

This is the shadow which gives this test its name. Thus we see that, when the axial ray X^3, (fig. 82) is directed to a point on the retina, at E^2, the left side of the bundle of rays will be cut off by the iris, and the pupillary space will appear dark on the opposite side. The same result obtains when the axial ray X^2, is directed toward the point on the retina at E^1. Consequently the shadow of the iris cannot be seen, and the dark part of the retina will appear to move in the same direction as the light is turned.

But it is not only this dark portion of the retina that seems to move, but we notice that the illuminated part of the retina moves also, and in the same direction, because, as the rays are reflected from the retina of the hyperopic

eye, they pass outward in a divergent direction, as shown in this diagram :

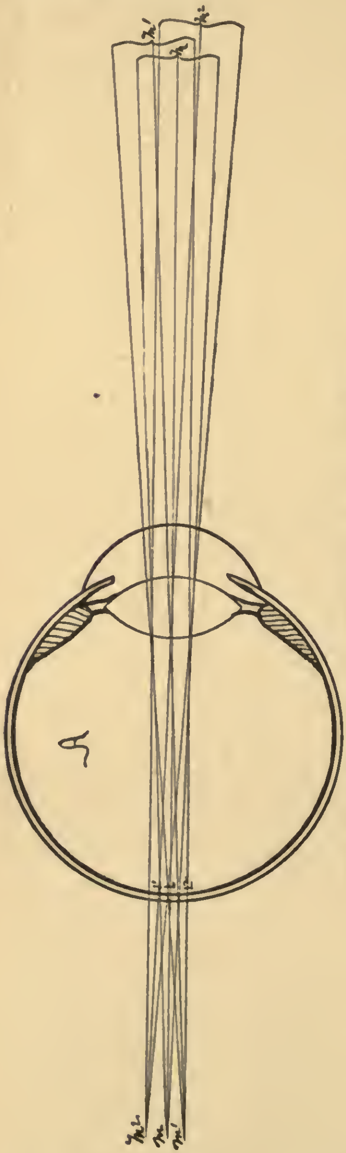


Fig. 84.—Retinoscopy : Emergent Rays, Hypermetropia.

These emergent rays appear to come from a point behind the retina and the image is erect, as if we illuminate that portion of the retina at L^1, —by turning the mirror to the right,—the image will appear to be at m^2, in the same direction the mirror is turned ; or, in which if we turn the mirror to the left, as at L^2, the rays will appear to proceed from the point m^1.

In myopia, with the plane mirror, we have the opposite effect, as the emergent rays from the retina, as they are refracted outward, are convergent ; so that if the myopia be of a greater degree than $\frac{1}{40}$ these rays will converge to the punctum remotum and there form an aërial image (inverted) of the retinal reflex, with the axial ray turning on the nodal point. Consequently, as the illuminated portion of the retina moves to the right, the aërial image as seen by the examiner will move to the left, and the curved shadowy portion of the non-illuminated retina will appear to move in the same

direction. I would illustrate this to you by the following diagram.

You will notice that the rays from the illuminated portion of the retina, at L^1, when the mirror is turned to the left, converge to the point m^1, and those from L^2, at the point m^2. Hence, in myopia the retina being illuminated the same as in emmetropia or hypermetropia, the emergent rays, having a focal point, must turn on the nodal point of the refractive apparatus at D, and appear to move in an opposite direction.

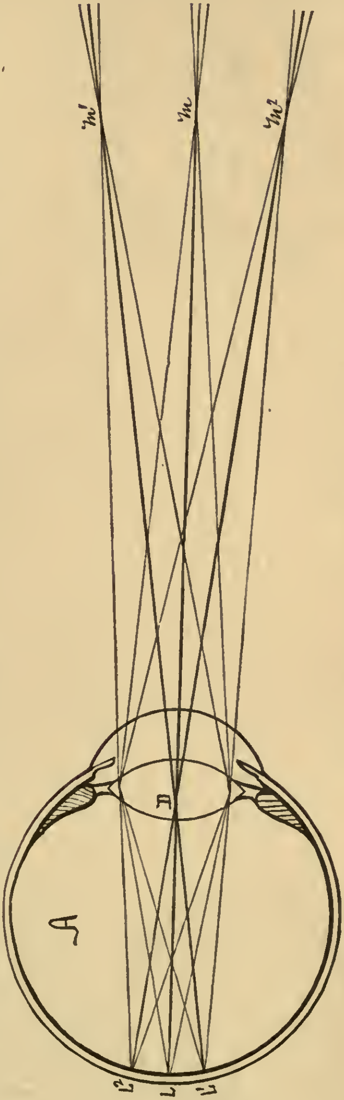


FIG. 85.—RETINOSCOPY: EMERGENT RAYS, MYOPIA.

To form a diagnosis, then, of the refractive condition of an examined eye, by the method of retinoscopy with the plane mirror, it will only be necessary to note that, if the retinal reflex moves in the same direction in which the mirror is turned, on its vertical or horizontal axis, you have hypermetropia; and that the strongest convex glass placed before the eye, as near the nodal point as possible, which will stop the movements of the reflex, will measure the amount of the existing hypermetropia.

Again, if the retinal reflex and the so-called shadow

move in an opposite direction, we have myopia; and the weakest concave glass placed before the examined eye, as near the nodal point as possible, will give the measure of the myopia.

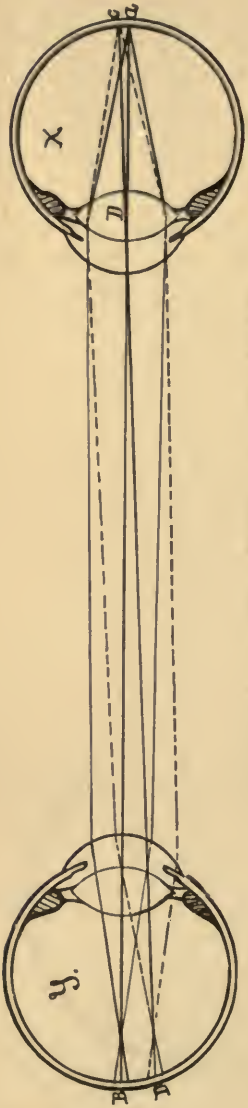


FIG. 86.—RETINOSCOPY: MYOPIA OF LOW DEGREES.

In using this test you must remember that the examiner's eye is placed at about 40 inches from the examined eye, so that the rays coming from a myopic eye of low degree, *i. e.*, less than $\frac{1}{40}$, cannot form an inverted aërial image in front of the observer. The converging rays will focus in front of his retina, and the image on the observer's eye will follow the direction of the axial ray from the examined eye.

You will understand this by reference to this diagram, showing the horizontal meridians of the examiner's and the examined eye. When the reflex comes from the point *a* in the eye *X*, the cone of light, as shown by the lines, will enter the eye *Y* convergent, and, being refracted, will form circles of diffusion on the retina of the examiner's eye at *B*. As we move the reflex to the left at *c*, the emerging cone of light with its axial ray will move to the right and form a diffused point of light on the examiner's eye at *D*. This, by a well-known law of the projection of the image, will appear to be at the left, in the position of *c*. The reflex moves in the same direction in low degrees of myopia.

How, then, can you decide between emmetropia, hypermetropia, or a low degree of myopia? If you will place a convex lens of 1 D before the examined eye, when you find that the reflex moves in the same direction as the mirror is turned, and it still follows the movements of the mirror, you must have hypermetropia. This glass would tend to make an emmetropic eye sufficiently myopic to change the movements of the reflex. Then try a convex glass of .75 D, and if the image moves in the opposite direction you must have myopia, as with + .75 D added to even a myopia of .25 D would make the rays cross in front of the examiner's eye, showing myopia.

Should you wish to make all your calculation exactly correct, you must add 1 D to the correcting glass in myopia; and in hypermetropia subtract 1 D, to find the amount of total error of refraction.

Or, we may simply move the position of the examiner back to a point beyond which it is almost impossible to have a myopia that would cause any possible symptoms of asthenopia. As if we have a myopia of $\frac{1}{60}$, by moving the mirror back from the patient beyond 60 inches you will then have the movements in the opposite direction. This is one of the advantages of the use of the plane mirror, and by this method of altering the position of the mirror you may measure the degree of myopia. The movements of the reflex will stop when the mirror is placed at the point of convergence of the emergent rays. To measure the myopia, if you have the movements in the opposite direction, you may bring the mirror nearer the examined eye until the movements either cease or become very uncertain. Then the distance of the mirror from the nodal point of the eye will give the degree of myopia, as, if the movements stop at 20 inches, then the ametropia equals $\frac{1}{20}$, at 10 inches $\frac{1}{10}$, and so on.

Having then decided that you have a case of ametropia

by the test of retinoscopy, you can readily estimate the amount of the error of refraction by placing a correcting glass before the examined eye, as near as possible to the nodal point, or, we will say, about in the position of the glass of spectacles when worn. Then observe the movements of the reflex as it passes across the pupillary space, and the glass which will cause these movements to cease,—or become so uncertain that we cannot tell positively in which direction the movements are,—will represent the condition of refraction in the examined eye.

Let us examine first an emmetropic eye in which the reflex is very bright, the movements very rapid and in the same direction in which the mirror is turned. Then if the examiner be seated at about 40 inches from the patient, place a convex glass of $\frac{1}{80}$ before the examined eye, and find that the movements are in an opposite direction, he will have emmetropia. But if the reflex be not so bright, with the movements still in the same direction that the mirror is turned, we must have hypermetropia. Then place stronger convex glasses before the examined eye, and if the movements be still in the same direction, the strongest convex glass which will stop the movements of the retinal reflex, or make them uncertain, will represent the total amount of existing hypermetropia in the examined eye.

Now, if the movements of the retinal reflex are in an opposite direction, then we must have myopia, and we will proceed as before to place concave glasses before the examined eye until the movements of the retinal reflex stops or becomes uncertain; and the weakest concave glass that will produce this effect will represent the amount of existing myopia in the examined eye.

This method is very simple, and with a little practice, particularly with the pupil dilated with atropine, will soon enable you to make a very nearly correct estimate of the

errors of refraction, both of myopia and hypermetropia. As a test to confirm your previous results with the test glasses, Snellen's letters, and the ophthalmoscope, it is very reliable and of great service to the ophthalmologist.

This brings us to the diagnosis of astigmatism by retinoscopy, and if you will remember this rule, you can easily estimate the astigmatic error: Simply test the two principal meridians of the examined eye, *separately*, in the manner explained above.

When we illuminate the eye with the plane mirror, and rotate the mirror on its vertical or its horizontal axis, we will notice the movements of the reflex as it passes across the pupillary space, followed by the shadowy crescent. If these movements are *with* the mirror in the vertical or horizontal meridians, then they must show hypermetropia; or, if *against* the movements of the mirror, myopia. After testing each meridian in this manner, noting the direction and rapidity of the movements, you will place a convex or a concave glass before the eye, according to the condition of refraction shown. Then, if there is any difference in the refraction of these two meridians, the spherical glass will only correct one meridian, and will represent the amount of error of refraction in that meridian, leaving the other still uncorrected. You will then proceed to add a stronger glass until the error is corrected in the other meridian, and the difference between the two glasses will be the amount of astigmatism.

In making these calculations, leave all the other meridians out of the examinations. As you correct one meridian, you must, if there be astigmatism, either under- or over-correct the meridian at right angles to the one you are testing. Remember, also, to place the axis of the correcting cylindric glass at right angles to the meridian you have tested by retinoscopy.

If we have a difference in the refraction of the vertical

meridian from that of the horizontal, we will notice that the spherical glass placed before the eye will correct the movements in one meridian, while in the meridian at right angles to it we require a stronger glass. If you find that the movements in the vertical meridian cease with $+\frac{1}{20}$, and that in the horizontal meridian we require $+\frac{1}{10}$, then we have a hypermetropia of $\frac{1}{20}$ in the vertical and $\frac{1}{10}$ in the other meridian, or an astigmatism of $\frac{1}{20}$ in the horizontal meridian. The glass that would make both meridians emmetropic is $+\frac{1}{20} \bigcirc + \frac{1}{20}$ cyl. axis vertical.

You will notice by this that the movement of the reflex and also of the shadowy edge are along the ametropic meridian; that the shadowy edge is parallel with the axis of the cylindric glass; and that the spherical glass placed before the eye which will stop these movements, in the meridian tested, will show the refraction.

As you test each meridian separately, it will make no difference as regards the refraction of the other meridians until you test them.

We will have the same results in compound myopic astigmatism, by using concave spherical glasses; only remember to use the weakest concave glass which will stop the movements in an opposite direction. Then calculate the difference, to find the amount of astigmatic error of refraction.

In simple astigmatism, with the movements only in one direction, either hypermetropic or myopic, you will notice that the convex or the concave glass will cause the movements to change in the emmetropic meridian. Then measure the astigmatic error as directed for simple error of refraction, but only noting the movements in the ametropic meridian.

These movements of the retinal reflex are very interesting, when the astigmatic error is at any other meridian than that of the vertical or the horizontal. As, though you

may rotate the mirror on the vertical or horizontal axis, yet you will find that the movements of the reflex will always be in the astigmatic meridian. If the ametropic meridian be at an angle of 45° from the horizontal, then, as you rotate the mirror on the horizontal axis, causing the cylinder of light projected by the plane mirror to move up and down, the movements of the reflex and shadow will be solely in the direction of the astigmatic meridian. So that the moment you illuminate the eye

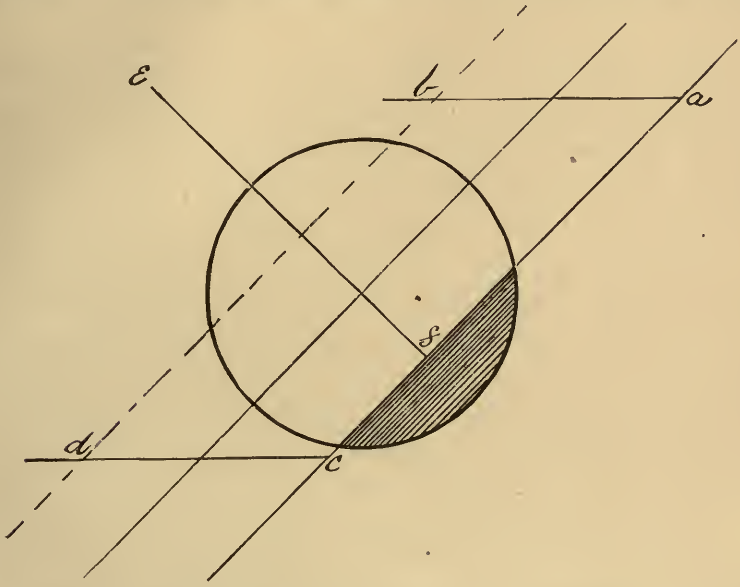


FIG. 87.—DIAGRAM SHOWING APPARENT DIRECTION OF THE RETINAL REFLEX IN ASTIGMATISM AT 45°.

and move the mirror, you can make your diagnosis of the astigmatism. This you will proceed to correct, in the two principal meridians, the same as if they were vertical and horizontal, using the strongest convex and the weakest concave glasses.

Burnett in his "*Treatise on Astigmatism*," explains this by stating that in astigmatism the shape of the circles of diffusion, formed on the retina by the illumination, is

not round as in simple refraction, but oval, with the long diameter in the direction of one of the principal meridians. Then as this oval moves across the retina, followed by the shadowy edge, it seems to move in the direction of the astigmatic meridian.

"Take a circular opening, as shown by the circle, and place behind it an object with a straight edge *ac*, at an angle of 45°, now advance this object in a strictly horizontal direction to *bd*, the apparent movement of the object will be, not from *a* to *b*, and *c* to *d*, but in the direction of the line *ef*, perpendicular to *ac*."

As a means of confirming my diagnosis of refraction with the test glasses, I have been well satisfied with the results obtained by the method of retinoscopy with the plane mirror, and now use it in all cases to confirm the examinations. Also in the examination of illiterate persons, young children, and those with whom we cannot use the other tests, you will find this very serviceable. Lastly, I would advise you that in the high degrees of refraction, particularly in myopia, if you cannot readily see the reflex at the distance of 40 inches, it will only be necessary for the examiner to move to a *nearer point*, until he can readily appreciate the movements of the retinal reflex. You will then proceed with the glasses placed before the examined eye. In these high degrees of ametropia, the emergent rays are so convergent or divergent, as the case may be, that, when they approach the examiner's eye, they are so scattered that but few will enter, and so the image formed on his retina will be very indistinct at the usual distance.

TENTH LECTURE.

PRESBYOPIA.

History—Definition—Causes—Influence of refraction on—Recession of near point—Manner of testing, in the emmetrope—In the hypermetrope—Bifocal and Franklin lenses—In myopia—In astigmatism—Second sight—Calculation of combined glasses—In anisometropia.

Gentlemen :—The time when glasses were first used for the improvement of vision dates back more than six hundred years. At that time they were used to improve the vision of old age,—a condition which we call *presbyopia.*

The history of the discovery and application of the lens to the improvement of vision is very interesting. Walter Alden, in his book on "The Human Eye," tells us that even at the excavations of the ruins of ancient *Nineveh* a "*rock crystal lens*" was found, and that in those days the people must have been familiar with the refraction of the rays of light by a lens. He says: "How could men attain such perfection in the other branches of mathematics, mechanics, etc., and yet leave the subject untouched, which each drop of dew sparkling in the sunlight of the morning would suggest?"

Referring again to Alden's history, we go back to the days of Roger Bacon, when he occupied the chair of philosophy at Oxford. He obtained some fine glass from Belgium, and with this he made some spectacles by grinding and polishing the lenses himself, and then imparted the secret to his friends. Cooper speaks of their having been worn by Henri Goethals when he was sixty years of

age,—glasses that had been given to him by his friend, Roger Bacon, before 1286. They were carefully preserved in those times, and Charles V., after his death in 1558, left among his valuables twenty-seven pairs of spectacles.

That they were valuable there is no doubt, and we often wonder what people did without them; but, as there were so few books at that time, the necessity for artificial aid to the normal eye was not felt as at the present time. Now they are a comfort and an assistance to almost every home; "for it is not too much to say that through the aid of spectacles we continue in the enjoyment, even in old age, of one of the most noble and valuable of our senses. They enable the mechanic to continue his labors, and the artist to display his skill in the evening of life; the scholar pursues his studies by their help, adding to the knowledge of others, and recreating his own mind with intellectual pleasures, thus passing days and years in satisfactory occupation that might otherwise have been devoured by melancholy, or wasted in profitless idleness."

In the history of spectacles we find that they were used for the relief of the vision of old age, to assist in the power to see clearly at near points, and that they have continued to the present day to be of assistance to us when this condition of presbyopia is felt in the daily occupations of life.

Presbyopia, you will find, commences generally in persons about forty years of age. It is first noticed by a recession of the near point, or, as the patient will tell you, he is compelled to hold his morning paper almost at arm's length to make the vision clear and distinct.

Donders, in his classical work on Refraction, (page 210), gives this definition of presbyopia: "The term presbyopia is therefore to be restricted to the condition in which

as the result of the increase of years the range of accommodation is diminished and the vision of near objects is interfered with;" and for its correction requires a convex glass of suitable focal power.

Let us now see why this range of accommodation is diminished, and why the near point recedes from the eye.

I do not consider this condition of refraction by any means abnormal, but simply the result of old age, just as gray hairs and other evidences appear in their proper time, to show that we are gradually advancing in years. We will therefore consider presbyopia as a normal condition of the eye which all must look for; that it will be influenced according to the refractive condition; and that it is due partly to changes in the curvature of the lens and loss of elasticity, but chiefly to insufficiency of the power of the ciliary muscle.

Presbyopia, in all cases, will vary according to the refractive condition of the eye. Hypermetropia will cause this recession of the near point to appear early in life, while in low degrees of myopia presbyopia will appear much later. You will also find that the state of the general health will frequently have a decided influence on the appearance of this condition.

For these reasons you will understand that we cannot lay down any rules or tables that will be of any practical value, except one: that you must test each case separately and carefully according to the condition of the refraction.

If we consider presbyopia in the emmetropic eye, and knowing that it depends on the recession of the near point, you will then find that this point begins to recede very early in life, perhaps about the age of ten years; but at that time it is still so near the eye that the gradual recession does not make any difference in our comfort, nor does the work of the eyes cause any symptoms of asthenopia.

At what point on the visual line, as this near point recedes, shall we mark the place where presbyopia begins? This question must be answered more from experience than from any positive facts. We find that when the near point recedes beyond 8 or 9 inches, then the presbyope finds that reading is not so comfortable, and they feel the desire to remove the paper or work from the eyes.

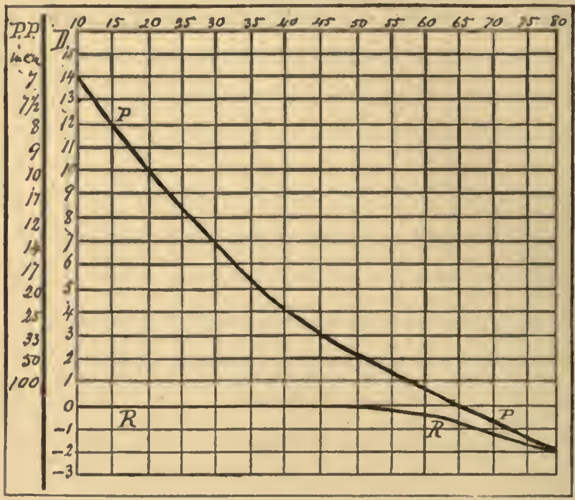


FIG. 88.—DIAGRAM OF ACCOMMODATION. (DONDERS.)

Showing the course of accommodation in an emmetropic eye. The figures at the top of the diagram indicate the age, those at the side the amount of accommodation, and the *P.P.* in centimetres; the oblique line represents the course of the punctum proximum, and the horizontal line that of the punctum remotum: the space between the two lines gives the amplitude of accommodation. From this diagram we can calculate the amplitude of accommodation possessed at any age. (Hartridge.)

We say, then, that presbyopia begins when the near point has receded beyond 8 or 9 inches (216 *mm.*) from the eye. As it passes that point and the symptoms of discomfort and fatigue present themselves, we must simply bring the near point back again within this arbitrary point, by the use of convex glasses.

In the emmetropic eye, under the usual conditions of health, we find that they require about + .5 D for each

additional five years beyond forty. As between 40 and 45 years, they require + .5 D, between 45 and 50 years, + 1 D, and so on. I think you will find this rule nearly correct; but, in practice, very few emmetropes consult an oculist—as regards their presbyopia,—but will find glasses to suit themselves at the optician's. It is therefore after they have tried various glasses, without satisfaction, that they will come to you for relief.

If I would give you a rule in the selection of glasses for presbyopia, in the emmetropic eye, I would say: Test each eye separately at 20 feet and, finding $V = \frac{20}{20}$, you may then order that convex glass which will enable them to read No. 1 *Jaeger's* test-type at 8 or 9 inches with comfort. Some of our patients cannot see the necessity of reading the *brilliant* type at a point so near the eyes; but it is very obvious that if in the normal eye, we enable a person to read at that distance, he can easily and with comfort read at a point farther removed to suit himself.

Presbyopia, in the normal eye, will require but little thought or judgment. We might consider it the primary part of the correction of the errors of refraction; but you will seldom be called upon to assist this insufficiency of the ciliary muscle, as it is so seldom that the aid of the oculist is needed.

What, then, does this condition of presbyopia imply? Simply that there is a weakening or failure of the power of the ciliary muscle to contract when objects or letters are brought near to the eyes, as the entering rays of light are so divergent that the contraction of the ciliary muscle, by its action on the curvature of the lens, is not sufficient to cause these divergent rays to focus upon the retina. Then, as the presbyope becomes older, we find another factor that will interfere with vision at near distances—that is, a loss in the elasticity of the lens; so that, though the ciliary muscle may contract, yet the lens

is not sufficiently elastic to accommodate itself to the relaxation of the capsule. It will retain almost the same curvature as when at rest, consequently in the emmetropic eye, it is only adapted for parallel rays.

We may then conclude that there is no change in the construction or the formation of the eyeball as we advance in life. The eye is still adapted for normal or parallel rays of light, when at rest, but simply that its region of accommodation is reduced by a recession of the near point, the eye being unable to adjust the refractive apparatus to vision for near objects.

Many presbyopes, however, will seek your aid. Their glasses did suit them at one time, but are not satisfactory now; or, if suitable, they cannot read as long or as steadily as before. This may occur in the emmetropic eye, but in that case the patient simply needs a stronger convex glass; for you will find that even with the glasses the near point has receded beyond the limit, requiring a stronger glass to enable him to read at 8 or 9 inches.

But the cases that will require your attention are those in which we have an existing error of refraction. Perhaps they have worn glasses for several years, and now, passing on to that age when presbyopia appears, they find that the glasses must be changed.

As hypermetropia is the predominant error of refraction, so will it complicate your cases of presbyopia. Simple hypermetropia causes the condition of presbyopia to commence much earlier than in the emmetropic eye; as, if the patient has been able to overcome the hypermetropia while the lens was soft and elastic, yet, as time goes on, the near point recedes with him much sooner than with the emmetrope, and he will require a weak convex glass for reading at night, before he is forty years old. Such a patient as he becomes older, say fifty-five years or more, will now require glasses to assist his hypermetropia. He

cannot now focus the parallel rays upon the retina, and consequently will require glasses for distant as well as for near vision.

How, then, shall we test such a case? You will first correct the absolute hypermetropia, by using that convex glass which will bring the distant vision to $\frac{20}{20}$, and with this glass you will see at what distance he can read the finest type, as No. 1 Jaeger. Then, if the near point has receded from the eyes beyond 9 inches, you will add to this glass another convex glass to bring the near point within 8 or 9 inches. The sum of these two glasses combined will give the amount of presbyopia, and the glasses needed for reading; while, if necessary, the glasses which neutralize the existing hypermetropia may be ordered to be worn constantly; except when reading. If your patient does not wish to be constantly changing the glasses, as the eyes are used for near or distant vision, you may order them made *bifocal*. The glasses that have the upper part of the glass cut from the lens required for distant vision, and the lower part from the reading glasses, are called the FRANKLIN lenses; or you may have both foci ground on one lens—the upper part for the distant vision and the lower for reading. These are called bifocal lenses.

Presbyopia also comes to those who are myopic, but now the myopia influences the presbyopia, so that the recession of the near point does not occur until much later in life. In very high degrees of myopia, where the far point lies at or nearer to the patient than 8 inches, presbyopia will never occur; but, as I will explain to you, he will need your advice in the selection of glasses when he feels the strain of the ciliary muscles.

Let us first consider those myopes of about $\frac{1}{20}$, or 2 D, when they use glasses only to improve their distant vision. At fifty they will begin to feel the necessity for some assistance when reading, and you will find the near

point has receded beyond 8 inches. A weak convex glass that will enable them to read at a suitable near point will be all that is necessary to relieve their presbyopia, while they will continue to wear the concave glasses for distant vision.

Again, take the myope of 5 to 8 D, and, though in time his near point will become the same as his far point, yet you will find that he cannot read with his glasses. They will make the rays of light too divergent. Now we want the effect of a convex glass, which we obtain by ordering a weaker concave glass, so that he can read at about 10 inches with comfort.

In those cases where you have the refraction complicated with astigmatism, it is more difficult to fit them correctly ; but, as we fit each meridian at the distant point, so must we fit them for the near point.

In presbyopia complicated with astigmatism of any degree, simply remember to find the two principal meridians ; then fit each meridian as if the entire refraction was of the same degree, as in using spherical glasses. After you have corrected the refraction for the distant vision, you will add to these glasses suitable convex glasses which will make the vision perfect and comfortable at the near point.

Let us consider, first, a case of simple or compound hypermetropic astigmatism, that has been wearing glasses for several years. We will find the amount of hypermetropic astigmatism, by the trial with glasses at infinity, and with this glass test the power to read *No. 1 Jaeger* at the nearest point. If you find this is beyond 8 inches, such case has become presbyopic and will need, combined with the distant glasses, a convex spherical glass that will bring the near point up to 8 inches.

A still more interesting class of cases are those of myopic astigmatism, particularly the simple forms, in

which you have one meridian myopic and the other emmetropic. Now, if we take each meridian separately, we find that in the myopic meridian they will not need a convex glass, as the refraction in that meridian is adapted for divergent rays, coming from the near point; but, in the opposite meridian, being emmetropic, they will require about the same convex glass as the normal emmetrope of the same age.

We can illustrate this with a case of simple myopic astigmatism of $\frac{1}{10}$, or more fully expressed, $V = \frac{20}{100}$, w. $-\frac{1}{10}$; cyl. axis $90^\circ = \frac{20}{20}$. Consequently we have myopia of $\frac{1}{10}$; in the horizontal meridian, and emmetropia in the vertical meridian. Now, if our patient be about fifty years of age, and his power of accommodation normal, he would require a glass of about 1. D focal distance. As he is emmetropic in the vertical meridian, so he would require a convex cylindric glass of 1. D for this meridian, with the axis of the glass placed horizontally; while, for the myopic meridian, as it is adapted for divergent rays coming from a point 10 inches in front of the eye, consequently at the near point of 8 inches, only the slightest effort of the accommodation is needed to assist the presbyopia. We will therefore order for the distant vision the above simple *concave* cylindric glass ($-\frac{1}{10}$), with the axis placed vertical, and for the reading distance a simple *convex* cylindric glass ($+\frac{1}{40}$), with the axis placed horizontal.

You must make the same calculations in cases of compound myopic astigmatism, only remember that the greater the amount of myopia the weaker the convex glass required, according to the age and bodily condition of your patient.

Before closing this lecture on presbyopia, I wish to speak to you of those remarkable cases of the recovery of the sight at a very advanced age, and called *second sight.*

I know that some persons are favored with such remarkable power of the ciliary muscle, that, though they may be hypermetropic, yet they will not need glasses until after fifty or more years of age; but, when you hear of a case where the reading power has seemingly returned after the age of about seventy years, you may be satisfied of about two conditions as the cause of this remarkable sight. If the case had a thorough examination, you would either find myopia, in which they never saw well at a distance; or there has occurred a slight swelling of the crystalline lens, due to commencing cataract, without perhaps any opacity of the lens substance. This condition would act on the divergent rays of light, as if a convex lens had been placed before the eye. You will at once see that the power of the ciliary muscles have not returned, but that a true pathological process is no doubt taking place.

You must in all cases first find the actual condition of the refraction; find out if there be any existing error, either hypermetropic, myopic, or any of the various conditions of astigmatism, and correct fully and exactly with a suitable glass. Then placing these glasses in your frame, —no matter what may be the combination,—place the glasses before the eyes and test their region of accommodation, finding the near and the distant point for reading easily No 1 *Jaeger* test-type. If you find that the near point has receded from the eyes, to a point beyond 8 or 9 inches, you should then add convex spherical glasses until they can read the finest type at 8 inches, and then calculate what glasses are required. This would be very simple if you have only used convex glasses for the distant vision, where you have hypermetropia or hypermetropic astigmatism. But if you have myopia, though you follow the same process of testing the vision, yet your calculations become somewhat more complicated.

Let me illustrate this to you by the following case,

both eyes being the same as $V = \frac{20}{200}$, w. — $\frac{1}{10}$ ⌒ — $\frac{1}{20}$, cyl. ax. 90° = $\frac{20}{20}$; patient's age fifty-five years. Now with this glass he reads No. 1 Jaeger at 12 to 20 inches, then his near point has receded beyond the point where presbyopia begins. We now add a convex spherical glass of $\frac{1}{40}$, and he can easily read the finest type at 8 inches. What glasses shall we order for this case? Let us make our calculations in each meridian separately, and we find in the vertical meridian for distance — $\frac{1}{10}$, to which we add + $\frac{1}{40}$, then $(-\frac{1}{10}) - (+\frac{1}{40}) = -\frac{1}{13\frac{1}{3}}$ for the vertical meridian.

In a horizontal meridian we have $(-\frac{1}{10}) + (-\frac{1}{20}) = -\frac{1}{6\frac{2}{3}}$ then add the convex spherical and we have $(-\frac{1}{6\frac{2}{3}}) - (+\frac{1}{40}) = -\frac{1}{8}$ for the horizontal meridian. The glass to be ordered is — $\frac{1}{13\frac{1}{3}}$ ⌒ — $\frac{1}{20}$, cyl. ax. 90°, for each eye. The cylindric glass being the same, and the spherical glass reduced, according to the strength of the convex glass required to take the place of the weakness in power of the ciliary muscles.

You may make this calculation much easier by using the metric system of numbering the glasses; as in the vertical meridian you have — 4 D, and in the horizontal meridian — 6 D, you simply take 1 D from each meridian, and we have — 3 D ⌒ — 2 D, cyl. ax. 90°.

Where you have the condition of *anisometropia*, or a difference in the refraction of each eye, this method will assist you very much, as you will then fit each eye separately and accurately for the distant vision, and, placing these glasses before the eyes, test them for the near point. Add your convex spherical glass which will bring the near point back to 8 inches, then make your calculations for each eye separately, and you will have a glass that, in the large majority of cases, will be suitable, and will correct their presbyopia.

You may also meet with some cases in which there may

be amblyopia, and they cannot read the finest type with any glass. In such cases you must ascertain the finest type which they can read, and using that as your test, find the nearest point, and if this be beyond 8 inches, you will use the convex glass that will bring their vision within the proper distance. While, should your case be so illiterate that he cannot read—and we meet many such cases in clinical work,—then find out for what kind of work he needs glasses, and give him the convex glass with which he can do that work clearly.

ELEVENTH LECTURE.

ILLUSTRATIVE CASES.

FROM PRIVATE AND CLINICAL PRACTICE.

Gentlemen :—I have endeavored to explain the different methods of examination of the eye for various errors of refraction, and the theory by which our results are obtained. We will now pass on to the application of the practical work to your patients by illustrated cases of the different errors which I have met in private or hospital practice, selecting those that will show you the different methods by which we arrive at our diagnosis, and the reasons why I should order certain glasses for general or special use.

I will not advise you to particularly notice the contour of the head or face, nor the length of the eyeball ; for though these various conditions may be associated with certain conditions of the refraction—as asymmetry of the face or head may denote astigmatism, while prominence or flatness of the eyeballs may denote myopia or hyperopia respectively—still in all cases you must depend primarily upon your careful test with the glasses and the confirmation of the result by the retinoscopic test and the ophthalmoscope.

If we study these cases in their relative frequency, I find from a reference to my statistics of the refraction of over 1,000 eyes examined by myself, *Dr. W. H. Fox*, and *Dr. G. H. Bull*, at the refraction room of the *Manhattan Eye and Ear Hospital*, during 1884 to 1886, there were :

683 cases hypermetropia,
108 " myopia,
95 " hyperopia with hypermetropic astigmatism,
60 " simple hyperopic astigmatism,
41 " compound myopic astigmatism,
31 " mixed astigmatism,
28 " simple myopic astigmatism,

while but very few were found to be emmetropic.

These results do not agree with a monograph by *C. R. Agnew, M.D.*, on "A Preliminary Analysis of Ten Hundred and Sixty Cases of Asthenopia," from the report of the Fifth International Ophthalmological Congress, September, 1876, and issued in 1877. In this monograph more than one-fourth of the cases he reports were emmetropic. I can only say that my cases were all carefully examined, most of them under the influence of atropine, and yet there were very few emmetropic; while more than one-half were hypermetropes of different degrees. This agrees much better with the report of the "Examination under Atropine of the Refractive State of Eyes with Normal Vision $\frac{20}{30}$, and Which Had Never Been Affected with Asthenopia or Inflammation," by *Prof. D. B. St. John Roosa*, in which he found 80 per cent. hypermetropic and only 20 per cent. emmetropic of the persons examined. Also a monograph by the late *Dr. Edward T. Ely*, "On the Examination of the Eyes of Very Young Children under Atropine," in which he found them nearly all hypermetropic.

I think we can conclude then, that the largest proportion of cases which will present themselves for your examination will be hypermetropic, and consequently this condition will require our attention first. Your cases will give you a varying history of their asthenopia: as, "The sight blurs; cannot read, or use the eyes, for any length of time; the eyes feel strained; they have head-

aches, pain in the eyeballs," etc., etc., and other expressions indicative of weakness and irritation.

CASE I.—Miss O., age sixteen, says she can only study at night for half an hour, when she has dull, throbbing pain behind the eyeballs. The eyes feel very tired, and the letters appear blurred. Can see well at a distance.

On testing the vision with Snellen's test letters, I find:

$$\text{R E, V} = \tfrac{20}{15};$$
$$\text{L E, V} = \tfrac{20}{15}.$$

If I now place a very weak convex glass before either eye the vision is blurred, so there is no manifest hypermetropia, nor can there be any myopia, as the vision is not reduced. I therefore examine the eyes by retinoscopy, and find a slight amount of hypermetropia, which is confirmed by the ophthalmoscope, showing about 1 D. She was now ordered a four-grain solution of atropine, one drop in each eye three times a day for three days—this is the usual solution that I use to stop the action of the ciliary muscle in accommodation. At the end of that time the eyes were again tested, and V was found to be reduced to $\frac{20}{30}$ in each eye. Placing now a convex glass of $\frac{1}{40}$ before each eye separately $V = \frac{20}{20}+$. Retinoscopy and the ophthalmoscope gave the same result on examination.

As the total hypermetropia was so small in this case I did not advise her to use glasses, confining my attention to the general health, and ordered a solution of sulphate of eserine, $\frac{1}{40}$ gr. to one ounce of water, dropped in each eye three times a day. Under this treatment she was relieved of all symptoms of asthenopia.

Donders does not advise the use of glasses in cases of hypermetropia of less than $\frac{1}{40}$, or 1 D. But you may meet with cases that will not be relieved without them. In the above case, had it been necessary, I should have

ordered a convex glass of $\frac{1}{80}$, or .05 D, for use in reading and sewing.

CASE II.—Miss M., age 15, now at school. Four months ago she could not see well at a distance; came on gradually, with a blur before the eyes. She could not study at night, as the light would hurt the eyes and V became blurred.

On examination I found:

$$\text{R E, V} = \tfrac{20}{20}, \text{ Hm. } \tfrac{1}{36};$$
$$\text{L E, V} = \tfrac{20}{20}, \text{ Hm. } \tfrac{1}{36}.$$

The ophthalmoscopic examination shows about 2 D hypermetropia. Solution of atropine ordered for two days, when the vision became:

$$\text{R E, V} = \tfrac{20}{100}, \text{ w. } + \tfrac{1}{18} = \tfrac{20}{20};$$
$$\text{L E, V} = \tfrac{20}{100}, \text{ w. } + \tfrac{1}{20} = \tfrac{20}{20},$$

showing a total amount of hypermetropia of about 2 D. She was now allowed to stop the atropine, and after ten days, to visual tests showed a manifest hypermetropia of $\frac{1}{30}$ in each eye. These glasses were ordered for constant use, and two months after she reports no symptoms of asthenopia.

You will find many cases similar to the above, and in young persons I would advise the use of atropine in all cases, to prove the amount of total hyperopia, as well as to make your test complete; but in persons of over forty years I would not advise you to put them to the inconvenience of the loss of vision by atropine. Nor is it necessary, as at that age the power of the accommodation is generally too low to interfere with a proper and satisfactory test with the trial glasses.

You will notice from these cases that it is not necessary to test the vision at the near point, as regards the ability to read the finest type, provided the distant vision be $\frac{20}{20}$, as the region of accommodation is nearly always the same as that of the normal eye; and that the strongest

convex glass they will accept, without any blurring of the vision at a distance, will generally relieve them of the strain of the eyes.

The next condition of refraction which will require our attention is that of myopia, and when free from any pathological condition at the fundus, as a low grade of choroiditis, you must order a glass for the different distances at which distinct vision is desired, or according to the degree of myopia. I would give glasses for different distances in high degrees, while they will only require a glass for the distant vision in low degrees, and for the medium degrees you may order the same glass for near and distant vision. Should your test with the glass be satisfactory and be confirmed by the ophthalmoscope, there will be no necessity to use atropine.

For instance, let me illustrate this by a patient who simply complains of diminished distant vision, as follows :

$$\text{R E, V} = \tfrac{20}{50}, \text{ w.} - \tfrac{1}{24} = \tfrac{20}{20}\text{ ; L E, V} = \text{same ;}$$

can read No. 1 Jaeger test-type at 4 to 24 inches without a glass. In this case I would only order $-\frac{1}{24}$ for distant vision only ; no glass being needed for reading.

Again, if we find that the vision in each eye is as follows :

$$\text{R E, V} = \tfrac{20}{200}, \text{ w.} - \tfrac{1}{10} = \tfrac{20}{20}\text{ ; L E, V} = \text{same.}$$

Now as the region of accommodation is reduced to a few inches, the patient cannot see clearly beyond the far point, of ten inches, so we may order this glass to be worn all the time, giving perfect vision at a distance, and also at the near point, by the exercise of a slight amount of increased accommodation.

Let us again consider a myopic case of a higher degree, as follows :

$$\text{R E, V} = \tfrac{20}{200}, \text{ w.} - \tfrac{1}{4} = \tfrac{20}{20}\text{ ; L E, V} = \text{same.}$$

We may order this glass for distant vision, but for the

near point this glass will cause the rays to be too divergent, with an undue strain on the accommodation. I think it best to give them a weaker glass for the nearer points of vision, as I have in one case ordered one glass for distance, one for music, and another for the reading distance. In the use of these glasses for reading the book should be held as far away from the eyes as possible, or as far as will make reading comfortable.

We will now examine a case that is complicated with astigmatism, as follows :

CASE III.—Miss Clara R., age 22. She has been wearing glasses for several years, but they are not suitable, nor do they relieve the pain in the eyeballs ; has blurring of the vision when reading ; has slight blepharitis.

This case will illustrate to us our third largest percentage of cases, from the following examination :

$$\text{R E, V} = \tfrac{20}{200}, \text{ w. } + \tfrac{1}{16}, \text{ cyl. ax. } 90^\circ = \tfrac{20}{70};$$
$$\text{L E, V} = \tfrac{20}{20}, \text{ Hm. } \tfrac{1}{36}, \text{ cyl. ax. } 90^\circ.$$

I found these glasses the best at the time after several trials with sphericals, but the test was not confirmed by the ophthalmoscope, and I was not satisfied with the result. I ordered the solution of atropine three times a day. After three days the result was :

$$\text{R E, V} = \tfrac{50}{200}, \text{ w. } + \tfrac{1}{14}, \supset + \tfrac{1}{13}, \text{ cyl. ax. } 100^\circ = \tfrac{20}{50};$$
$$\text{L E, V} = \tfrac{20}{200}, \text{ w. } + \tfrac{1}{9} \supset + \tfrac{1}{30}, \text{ cyl. ax. } 80^\circ = \tfrac{20}{20}.$$

The ophthalmoscopic examination shows in the R E + 3 D vertical and + 5 D horizontal ; L E, + 4 D vertical and + 5 D horizontal. After the effects of the mydriatic had passed off, she accepts the following glasses :

$$\text{R E, V} = \tfrac{20}{200} \text{ w. } + \tfrac{1}{36} \supset + \tfrac{1}{16}, \text{ cyl. ax. } 100^\circ = \tfrac{20}{50};$$
$$\text{L E, V} = \tfrac{20}{20} \text{ w. } + \tfrac{1}{36} \supset + \tfrac{1}{30}, \text{ cyl. ax. } 80^\circ = \tfrac{20}{20}.$$

These glasses were ordered for constant use, both for distant and near vision. Several months after, she reported to me that the glasses had relieved her asthenopia.

In this case you will notice a certain amount of *amblyopia* in the right eye; that is, the vision, after correction with the proper glasses, did not reach the normal standard of $\frac{20}{20}$, but remained at $\frac{20}{50}$. We frequently find this condition when testing cases of hypermetropia, as I have explained in the lecture on that subject. You can only recommend the glass that will give the best vision at the distant point. By the use of atropine, in this case, I was able to obtain the exact meridians of the astigmatism, finding it at 90° before the atropine was used; when under its influence, the meridians at which I could get the best vision were those shown in the examination, changing the inclination of the axis of the cylindric glass toward each temple.

CASE IV.—Miss E., age 26. One year ago, after doing some very fine work, she had a feeling of fulness in the left eye, with blurring of the vision. This blurring has continued with pain in and around the eyes, and lachrymation. Has constant pain referred to the top of the head. She has never worn glasses.

On testing the eyes with the trial glasses, I found this result:

$$\text{R E, V} = \tfrac{20}{20}, \text{ Hm. } \tfrac{1}{48};$$
$$\text{L E, V} = \tfrac{20}{20}, \text{ Hm. } \tfrac{1}{48}.$$

As this examination was not satisfactory, while the ophthalmoscope showed a certain amount of astigmatism, I ordered atropine, to be used four days, with the following result:

$$\text{R E, V} = \tfrac{20}{70}, \text{ w. } + \tfrac{1}{48}, \subset + \tfrac{1}{48}, \text{ cyl. ax. } 80^\circ = \tfrac{20}{20};$$
$$\text{L E, V} = \tfrac{20}{70}, \text{ w. } + \tfrac{1}{48}, \subset + \tfrac{1}{48}, \text{ cyl. ax. } 100^\circ = \tfrac{20}{20}.$$

The ophthalmoscope and the test by retinoscopy gave the same results. She was then tested with the stenopæic slit, which placed at 180° with $+\frac{1}{24}$, V $= \frac{20}{20}$, and at 90° with $+\frac{1}{48}$, V $= \frac{20}{20}$, showing that in the vertical meridian, there was a certain amount of hypermetropia, and in the horizontal meridian, about 1 D. Now, the vertical meridian

was not emmetropic, but after the effects of the atropine had ceased, she would not accept any spherical glasses, so I ordered the cylindrics of the full strength accepted when under atropine. She was given this glass :

R E, $+\frac{1}{48}$, cyl. ax. 80° ;
L E, $+\frac{1}{48}$, cyl. ax. 100°.

You may ask, How do I decide that these glasses give the best vision ? Well, we know that the patient cannot be myopic, as the distant vision is about normal and is not made worse by weak convex glasses. I first select the strongest convex glass which will make any improvement in the vision at infinity. Placing this before the eye, I now try if they can see all the lines clearly on the card-test for astigmatism (*Green's*), and find that the horizontal lines are most distinct. Placing a convex cylindric glass before the spherical, and turning its axis from the right to the left until all the lines appear equal, I use then the test-letters (*Snellen's*), and find the strongest convex cylindric which the patient will accept. This done, I now reduce the spherical to see if I have over-corrected the meridian of least ametropia.

As in this case after the use of atropia, I found that she would only accept the cylindric glasses, the total amount of her hyperopia being too small to need correction and give satisfactory vision.

You will again notice that in these tests for hypermetropia I have made no mention of the near vision. Why so ? Because I do not consider it essential, as you will always find in young persons the amplitude of accommodation is sufficiently great to give them perfect near vision, their asthenopia arising only from the excess of accommodation required at reading, etc. So that, if you stop this strain, and neutralize their manifest hypermetropia only, you will relieve their asthenopia.

In older persons, as they have passed the age of forty, and presbyopia, or old-age sight, comes on, then you must test them for their near vision, giving them glasses for both near and distant sight. Take any of these four cases that I have recorded, and, as they become presbyopic, you will have to add to the glasses which correct their refraction suitable convex spherical glasses to bring the near point within the distance at which they are accustomed to read.

I would illustrate this to you as follows:

CASE V.—Mrs. S., age 40, has worn glasses for 12 years, but, though they relieved her at first, she now has asthenopia, with headache, and to see well at night the eyes feel strained.

I find on examination and the test with glasses that her vision at 20 feet is only $\frac{20}{30}$, and with a convex spherical of $+\frac{1}{30}$, $V = \frac{20}{20}+$, shows an absolute hyperopia of more than 1 D. But with this glass she can only read No. 2 of Jaeger test-type at 14 inches, so we must assist the action of accommodation still more by stronger convex glasses. Placing now $+\frac{1}{15}$ before each eye, or adding $+\frac{1}{30}$ to the glasses which correct her absolute hypermetropia, she can now read No. 1 Jaeger at 8 inches. I order for her distant vision $+\frac{1}{30}$ and for her near vision $+\frac{1}{15}$.

CASE VI.—Miss S. S. has always been near-sighted, and worn glasses for seven years, but only for distant vision. When reading half an hour, she has pain in the eyes and thinks they are getting worse. She holds her book at about 8 inches from the eyes. Never succeeded in getting glasses suitable to read with.

Her distant vision is only $\frac{28}{00}$, and on testing the eyes separately I find the vision as follows:

$$\text{R E, } V = \frac{8}{200}, \text{ w. } -\frac{1}{10}, \; V = \frac{20}{40}.$$

I now add the concave cylindric and find that

$$\text{with } \frac{1}{18}, \text{ cyl. ax. } 160^\circ, \; V = \frac{20}{20} -.$$

So that she has a myopia of $\frac{1}{10}$, in the meridian of 160°,

and about $\frac{1}{6}$, in the meridian of 70°, or at right angles to the axis of the cylindric glass.

$$\text{L E, V} = \tfrac{4}{200},\ \text{w.} - \tfrac{1}{9} \frown - \tfrac{1}{14},\ \text{cyl. ax. } 20^\circ = \tfrac{20}{20} -.$$

About the same as in the right eye, only you will notice that there is a similar position in reference to the axis of the cylindric glasses; the R E being at 160° and the L E at the corresponding angle of 20°. As these glasses indicate rather a high degree of myopia in one meridian, I examine her with the other tests, as the ophthalmoscope, retinoscopy, and the stenopæic slit, all of which confirm the result. But if these tests do not agree, as a part of the myopia may be due to spasm of the ciliary muscle, you should then place your patient under the influence of a mydriatic. In this case, to confirm my examination, and as it is advisable to do in all cases of astigmatism, I order the four-grain solution of atropine, and on again testing her with the trial glasses I found the same result.

Now, as the general myopia was only $\frac{1}{10}$,—a glass that we can order for near and distant vision,—I order these compound glasses to be worn all the time; and she reported her glasses satisfactory, with relief from her headache and pain in the eyes when reading.

You will find many cases that will represent the errors of refraction which I have illustrated, with different degrees of ametropia; with the axis of the cylindric glasses in the different meridians, most of them will be at 90°, next at 180°, and the rest between these two meridians, with generally a symmetrical relation in the axis of the cylindric glasses. But, should you find the axis the same in both eyes, as 45° in each, I would advise you to examine them very carefully, to exclude all source of error, and to test the near vision in reference to the *shape* of certain objects, as a book or any object with right angles.

There are certain conditions of the refraction that may

be concealed, as the test with the trial glasses will give an entirely different result from the examination with the ophthalmoscope. This can only be due to a change in the curvature of the lens, caused by the action of the ciliary muscle. I will illustrate it to you in this case :

CASE VII.—Miss K., age 20. This patient has a constant blurring of the vision, which she has noticed lately. Has occasional sharp pains in the eyes. She can read for about twenty minutes, when the eyes feel tired. Thinks she is getting near-sighted. This pain may be due to the contraction of the ciliary muscle.

There is no doubt that from constant study persons become near-sighted, and this is apt to take the progressive form. (See myopia.) But this case presents a train of symptoms too recent in their history, while the asthenopia would indicate hypermetropic refraction. Let us see what the test will show :

$$\text{R E, V} = \tfrac{20}{30}, \text{ w.} - \tfrac{1}{48}, = \tfrac{20}{20};$$
$$\text{L E, V} = \tfrac{20}{40}, \text{ w.} - \tfrac{1}{42}, = \tfrac{20}{20}.$$

She would not accept any convex glasses, as even the weakest would make the letters more indistinct ; but the small amount of apparent myopia led me to suspect a different refraction. I then tested her with the ophthalmoscope and by retinoscopy : both tests indicated hypermetropia of about 1 D. This would indicate that the refraction of the eyes must be different when they are in active use or when examined in the dark room. I ordered the solution of atropine three times a day, for five days, with this result on examination :

$$\text{R E, V} = \tfrac{20}{40}, \text{ w.} + \tfrac{1}{42}, = \tfrac{20}{20};$$
$$\text{L E, V} = \tfrac{20}{50}, \text{ w.} + \tfrac{1}{36}, = \tfrac{20}{20}.$$

This result was fully confirmed by the other tests, and the myopia had disappeared.

If you will remember the lecture on myopia and the accommodative form, I endeavored to explain to you why these cases should present this apparent myopia. The

vision is at once brought up to the normal standard by the convex glasses and the action of atropine. We know that this drug stops the action of the ciliary muscle, and we know that by a spasm of the ciliary muscle the lens would become more convex. This would make the refractive power much greater, and so will focus the rays of light from infinity at a point in front of the retina. After using the atropia for a few days it was discontinued. At the end of about ten days the action of the accommodation had returned, and all evidences of the myopia had disappeared. She then accepted and preferred the weak convex glasses, and I ordered $+\frac{1}{80}$, for each eye, to be worn constantly until relieved.

You will generally find this condition associated with hypermetropia in young persons; though you may find it in the emmetropic as well as in the myopic eye. In myopes it is shown by their requiring a much stronger concave glass than is confirmed by the other tests. The ophthalmoscope may only show myopia of $\frac{1}{20}$, and yet they will require $-\frac{1}{10}$, to read $\frac{20}{20}$. In all these cases of suspected spasm of the accommodation, you must stop the action of the muscle of accommodation by a mydriatic, of which atropine is the best. If the spasm does not yield readily to the action of the medicine, keep them under the influence of the drug until all symptoms of the spasm have disappeared.

These cases are particularly interesting in the results of your examinations and the relief they will obtain by wearing the proper glasses; while a mistake in your diagnosis and the ordering of concave glasses would only tend to increase the pain and discomfort.

Another class of cases that we meet, presenting some symptoms the opposite to those of the spasm, is shown in the following case, where we have the ciliary muscle again at fault:

CASE VIII.—Master James B., age 12. He has lately recovered from an attack of sore-throat that was supposed to have been diphtheritic. He now complains that he cannot see the black-board at school, nor can he possibly see to read at any distance.

The parents are always very much alarmed at the loss of the sight in these cases; but you can easily show them with the proper glass that the vision is perfect at both near and distant points. Let us test this case with the glasses, and we find as follows:

$$\text{R E, V} = \tfrac{20}{100}, \text{ w.} + \tfrac{1}{15}, = \tfrac{20}{20};$$
$$\text{L E, V} = \tfrac{20}{100}, \text{ w.} + \tfrac{1}{14}, = \tfrac{20}{20}.$$

He cannot read Jaeger's test-type at any distance; but if we place glasses before each eye, convex, of 8 inches focal distance, he will readily read No. 1 Jaeger, the finest type, at about 10 or 11 inches. With such results there can be no fault at the fundus of the eye, and the trouble must be due to deficiency in the action of the muscle of accommodation.

You will notice that this case presents all the evidence of hypermetropia, under the influence of atropia; or the condition of refraction which we find in elderly persons, and the power of the ciliary muscle is about nil. There is, in fact, an almost complete paralysis of the muscle of accommodation. The pupils are slightly affected, there will be slight dilatation, and they will respond but feebly to the action of light; showing that the ciliary branches of the third nerve which supplied this muscle and the iris were affected by the action of the diphtheritic poison.

How will we treat these cases? I would not advise you to order glasses at first, but to try the effects of time and the use of a suitable tonic to the general system; for which I prefer the muriate tincture of iron, 10 drops three times a day. If your patients should be emmetropic, or have a slight degree of hyperopia, they will rapidly improve under the use of the tonic, and the vision will be

restored; but should they present a high degree of hypermetropia, as this little patient, you may order a glass which will correct their refraction for distant vision, to wear until all symptoms of weakness in the muscle of accommodation have disappeared. I would not order glasses for the reading distance unless necessary, but wait until the eye has recovered the power of accommodation.

While speaking on the subject of the loss of the accommodative power, let me present to you the following case. This case was reported by myself some years ago, and presents a rare condition, particularly interesting as regards the results of the examination. It is the only case of the kind in the number that I have examined in the office and at the hospital. I report it in full, that you may appreciate the different methods by which the eye was examined:

Case IX.—Mrs. M. A. S., age 23, gave me the following history. She first went to school at the age of seven years, and at that time, when studying, would always place her books as far away from the eyes as possible, or stand away from the teacher; while the other children would be at the teacher's knee. This continued, and as she advanced in age, she would sew and read at arm's length, so that her work would be constantly slipping off her lap. She would try to bring her work or book nearer, but vision would blur, and at once she was compelled to place the work further away. She never suffered from any of the acute diseases of childhood, as scarlatina or diphtheria, and only a slight attack of measles; while since then she has always had good health. The other members of her family have good eyesight, except one sister, who has been troubled with a medium degree of hypermetropic astigmatism; while her mother did not become presbyopic until she was over 50 years. Mrs. S. can read for several hours without material fatigue, provided she holds the book at a distance of about two feet from the eyes; and always prefers to read in a medium light, as a bright light is too dazzling. She has sometimes felt slight attacks of pain, referred to the balls of the eye, when reading for several hours, but did not consider that she had any particular trouble until she came to me with a slight attack of catarrhal conjunctivitis, that yielded readily to treatment.

On ophthalmoscopic examination the fundus appeared perfectly normal and the media clear; with a slight amount of hypermetropia, about 1 D. On testing her distant vision it was found to be:

$$\text{R E, V} = \tfrac{20}{20}, \text{ Hm. } \tfrac{1}{60};$$
$$\text{L E, V} = \tfrac{20}{20}, \text{ Hm. } \tfrac{1}{60}.$$

Her near point with No. 1 Jaeger was found at 20 inches, and the far point, with the same type, at 30 inches, in each eye; with a slight blurring of the vision in the right eye when reading very fine type.

She has homonymous diplopia at a distance of 20 feet, with a prism of 12° base upward, placed over either eye. This is corrected with a prism of 3° base outward. The internal rectus can only overcome a prism of 8°, and the strength of the external rectus is represented by a prism of 5°.

The *positive* part of her accommodation shows only $\frac{1}{20}$, and the *negative* part $\frac{1}{20}$, for binocular vision, with the visual axes fixed at her near point of 20 inches. Her range or power of accommodation is only about $\frac{1}{15}$, with a region of accommodation, with No. 1 Jaeger test-type, of 10 inches. This exists only at arm's length, or 20 to 30 inches from the eyes.

She was placed under a four-grain solution of atropia for four days, instilled three times a day, when the distant vision in each eye had fallen to $\frac{20}{40}$, and with a convex glass of 36 inches focal distance vision was brought up to normal, or $\frac{20}{20}$; showing a total hypermetropia in each eye of $\frac{1}{36}$.

In looking over this history and seeking for an explanation of the results contained therein, and endeavoring to arrive at a definite diagnosis, we are compelled to do so by exclusion, or by the negative results. While the present symptoms would indicate the existence of a par-

tial paralysis of the ciliary muscle, we can find no cause in her past history for any such conclusion, as this condition has existed since early childhood, when she was not afflicted with any disease to cause partial paralysis.

I am inclined to think, as we study the various phenomena presented by this case, that there is no pathological condition existing whatever; that when the visual axes are fixed on infinity, her slight degree of hypermetropia is overcome by the action of the ciliary muscle and we have vision = $\frac{20}{20}$, or normal; but that, when the vision is changed to a nearer point and divergent rays enter the eyes, the normal action of the ciliary muscle fails to respond, the vision becomes blurred, and No. 1 Jaeger test-type can be seen only at arm's length, or from 20 to 30 inches. This conclusively shows that there must be an almost total absence of any accommodative power. This is particularly shown in the right eye, from the fact that she frequently complains of a blurring of the vision in that eye, with dilatation of the pupil.

If we compare the results obtained in this case with those of the normal eye, both as regards the *extrinsic* and *intrinsic* muscles of the eyes, they will be found below the standard. The power of the internal recti, as shown by the test with prisms, is only about one third the strength of the normal muscles. She can only fuse the image of a candle flame with a prism of 8° with the base outward, while the normal standard exists at about 25° for the internal rectus.

I consider that this weak condition of the muscles of adduction is probably due to the fact that her near point is so far removed from the eyes that the muscles have had no stimulus to develop their contractile power to the normal strength and action.

As regards the intrinsic muscle, or the muscle of accommodation, to all the tests to which it was subjected it

failed to respond. Comparing the positive and the negative part of the accommodation, or the relative range, and we find it only as 1 to 1; while in the normal eye it should be as 2 to 3. In my eyes, with the visual axes fixed at the same angle, the relative range is about as 1 to 2.

You can readily measure this relative range of accommodation in your eyes by placing No. 1 Jaeger test-type at a fixed point, say 15 inches, and then placing the strongest concave glass before each eye for the positive part, and the strongest convex glass for the negative part, through which you can read the type easily. The concave glasses will increase the action of the accommodation, while the convex glass will cause it to relax.

Also examine this patient's binocular range of accomodation, and it falls to about $\frac{1}{20}$; *i. e.* with a convex glass of $\frac{1}{20}$ placed before each eye, would give rays of light coming from 20 inches, her near point, as if they came from infinity. This is very far below the normal range of $\frac{1}{4}$, showing that the accommodative power, with the convergence of the visual axes, is very small. This is also shown in the region of accommodation, with No. 1 Jaeger test-type, existing at 20 to 30 inches from the eyes—a region too far removed and too small to be of any practical service whatever.

As it is a self-evident fact that in this case there is an almost entire absence of any accommodative power, it would be well to again consider, as we have in the previous lecture, what are the essential elements concerned in that act.

The normal or emmetropic eye, when all its refractive elements are at rest, will so bend rays of light from infinity that they will exactly focus on the retina at the macula lutea. They there will produce an exact inverted image of the object to which the visual axes are directed. But as this object is brought nearer to the eyes, the rays

become more and more divergent and will focus behind the retina, producing on that sensitive layer of nerve cells circles of diffusion, provided the refractive apparatus remain at rest and the refractive angle continue the same. But the inherent faculty of the eyes will abhor any blurred vision, as nature is said to "abhor a vacuum," so, as the object is brought closer to the eyes, the act of accommodation takes place, the eye adjusts its refractive power to the vision at a nearer point, and will so bend the rays of light that they will exactly focus upon the retina.

To accomplish this act, the intrinsic muscle of the eye contracts (see Lecture I.), whereby the zone of Zinn is relaxed and the lens pushes forward the anterior capsule by its elasticity. This increases the refractive power so that it can exactly focus the divergent rays of light that proceed from an object brought nearer the eye.

But in this case we have a condition of hypermetropia, or congenital shortening of the eyeballs, so that the ciliary muscle must contract to focus parallel rays and make distant vision perfect. But there its power practically stops, and we are compelled to conclude that the fault must lie in the diminished action of the ciliary muscle. I should think that there must be a congenital deficiency of the circular fibres of that muscle, or a condition of muscular atrophy occurring in early childhood. Hence the only diagnosis possible: an almost total deficiency of the accommodative power of the eyes,—probably congenital.

The only treatment for the relief of this case can be by placing before the eyes convex glasses, so as to bring the near point within a distance of about 10 or 12 inches from the eyes, which on trial was found to be $+\frac{1}{24}$. This glass I accordingly ordered for each eye.

I have reported this case to you fully, as it presents

some very interesting and instructive features for our study, while it is an extremely rare one. We will now proceed to study some cases that present unusual features in prescribing glasses.

In prescribing glasses for persons past the age of forty years, when they become presbyopic, you will find this condition frequently complicated with some of the errors of refraction that have existed before that time, and which must be taken into consideration. They will require very different glasses from those usually ordered for the emmetrope. I will illustrate this to you by the following cases :

CASE X.—Mr. S. M., age 50, has worn concave glasses for many years, but only to improve his distant vision. His glasses are — $\frac{1}{20}$ for each eye. He complains that he cannot read comfortably except at about 20 inches from the eye.

His distant vision is found to be $\frac{20}{20}$, each eye, with — $\frac{1}{20}$. There is no increase in the myopia, but he cannot read No. 1 Jaeger except in the region of his far point, so that he has very little power in the accommodation. With + $\frac{1}{20}$ he readily reads No. 1 Jaeger test-type at 8 inches, so that he will require a convex glass (+$\frac{1}{20}$) for reading, and a concave glass (— $\frac{1}{20}$) for his distant vision. In the higher grades of myopia you will find that they need a weaker concave glass, as in the case of a myope of $\frac{1}{8}$ or $\frac{1}{10}$. Their far point lies at the distance that the presbyope's near point should be, and the weaker glass will give them a larger and more distant region of accommodation.

A still more interesting case is the following :

CASE XI.—Mr. J. A., age 50. Although his glasses have been suitable for many years, he now finds that, when reading, the eyes feel tired and his near vision is not satisfactory.

I find that the glasses he is now wearing are simple

concave cylindrics of $\frac{1}{20}$ in the horizontal meridian. With these glasses his vision is as follows :

$$\text{R E, V} = \tfrac{20}{70} \text{ w.} - \tfrac{1}{20}, \text{ cyl. ax. } 70^\circ = \tfrac{20}{20};$$
$$\text{L E, V} = \tfrac{10}{70} \text{ w.} - \tfrac{1}{20}, \text{ cyl. ax. } 110^\circ = \tfrac{20}{20}.$$

The examination with the ophthalmoscope gives the same degree of refraction. I can see the horizontal vessels through the aperture, being in the meridian of greatest ametropia, but I cannot see the small vertical vessels except with — 2 D. With this glass all the vessels are clearly seen. We can then decide that his glasses are correct for distant vision, but they do not suit for reading. Now in this case we must consider what would be the result in an eye where the entire refraction was the same in each of the principal meridians.

If we take the horizontal meridian we find myopia of $\frac{1}{20}$, and at his age, as his far point for that meridian is only 20 inches, he would not require a glass, while in the vertical meridian we find that he is emmetropic. Now, at fifty years, the emmetrope will require a convex glass of about $\frac{1}{24}$ ($1\frac{1}{2}$ D). In this case this indication is met in the simple convex cylindric glass of $+\frac{1}{24}$, and if we place this glass before his eyes, with the axis over the myopic meridian at 180°, or horizontal, we find that he can read No. 1 Jaeger at 8 inches with comfort. I would order this glass for reading only, while he will continue to use the other glasses for distant vision.

These cases are not uncommon, and show you that in astigmatic eyes, when they have become presbyopic, you must correct each meridian just as an eye of the same degree of refraction.

You may have various complications in the different meridians, as I have shown you in the case of astigmatism, where the patient, when young or under the age when presbyopia comes on, will be suited with those glasses

that neutralize the exact condition of refraction which exists in each principal meridian. But, when presbyopic, we must estimate and treat each meridian separately, prescribing that glass which will make the refraction of each meridian the same as in the emmetropic eye, and add to this the convex glass that will restore the loss in the amplitude of the accommodation.

Another very interesting class of cases is that of amblyopia, or dull vision, in one eye. This condition is generally congenital in its origin and then presents no evidence of any pathological process in the eye. I will illustrate it by the following:

CASE XII.—Mrs. O., age 58. She has worn glasses for the past sixteen years, has changed them several times, but the eyes still give her some discomfort with pain in the "back of the eyeballs." She tells me that there is no vision in the left eye.

I find that the reading glasses she wears are for R E $+\frac{1}{10}$, ⊂⊃ $+\frac{1}{48}$, cyl. ax. 90°, and for L E a plain glass. I then tested her distant vision and found it to be:

R E, $V = \frac{20}{200}$, w. $+\frac{1}{36}$, $+\frac{1}{48}$, cyl. ax. 90° $= \frac{20}{30}$;
L E, $V = \frac{1}{200}$, eccentric vision, improved with $+\frac{1}{10}$ to $\frac{20}{200}$.

With this glass she can read No. 5 Jaeger test-type at 24 inches, and if we now add a convex glass over the right eye for her condition of presbyopia (about $\frac{1}{13}$), and use the $+\frac{1}{10}$ over the left eye to assist that as much as possible, we then have this glass:

R E $+\frac{1}{10}$, ⊂⊃ $+\frac{1}{48}$, cyl. ax. 90°; and
L E $+\frac{1}{10}$.

With this glass she can read No. 1 Jaeger at 9 inches easily and with comfort. I ordered these glasses for all reading and near work, while I advised her to wear the glasses that corrected her compound hypermetropic astigmatism for distant vision, so as to relieve the strain on the accommodation.

This case shows : First, that a mistake was made in not correcting the refraction of the amblyopic eye as far as possible. Second, that, no matter how defective the vision may be in either eye, we should correct any error of refraction, so that both eyes may work together. Test and fit each eye separately, and then select that glass with which you find the best and clearest vision at the proper distance. In the above case I heard from Mrs. O. several months after the glasses were ordered, and she had entire relief from all her discomfort and pain. Because the vision is much reduced in one eye, from any cause, we must not leave the vision of that eye uncorrected, but find the glass which will give the best and most distinct vision, and order your glasses accordingly.

You will also meet a more interesting and difficult class of cases in those persons who have astigmatic eyes, generally hyperopic, but with the axis of the correcting cylindric glass of the *same meridian in each eye*. I have already told you that in the largest number of cases the axis of the astigmatic glass is at 90° or 180°, then you will find them at 45° in one eye and 135° in the other, or inclining toward the nose or temple in each eye. But you will occasionally meet with a case where you will find the axis the same in both eyes, say at 45°—one axis inclining toward the nose and the other towards the temple. In these cases I would advise you to test them carefully at their near and distant points of vision, both as regards the letters and the size and shape of objects, fitting them first for distant vision, and then to see if these glasses will also give perfect vision as regards letters and the shape of objects at the near point. I would illustrate this to you with the following case, reported by myself in the *Quarterly Bulletin* of the New York Post-Graduate School, vol. ii., No. 3, 1887, as follows :

Case XIII.—Mr. John M., age 29, consulted me some six months

ago in reference to his sight, stating that his vision had not been satisfactory for several years, his work being that of cutting marble and other stones in lines and curves. At night he could not read without pain in and around the eyeballs, though his eyes did not pain him when at work in the daytime. His vision on testing was as follows :

R E, $V = \frac{20}{50}$, Hm. $\frac{1}{30}$, reads No. 1 Jaeger at 7 inches ;
L E, $V = \frac{20}{100}$, accepts no glasses, reads No. 6 Jaeger at 9 inches.

He thinks the cylindric glasses improve his vision. On examination with the ophthalmoscope I find hypermetropic astigmatism, with some slight myopia in one meridian, and by the test of retinoscopy, decided astigmatism at the meridian of 135° R E, and 45° L E. After using the solution of atropine two days he was again tested, as follows :

R E, $V = \frac{20}{50}$ —, w.— $\frac{1}{60}$, + $\frac{1}{18}$, cyl. ax. 45° = $\frac{20}{50}$ + ;
L E, $V = \frac{20}{200}$, w. — $\frac{1}{60}$, + $\frac{1}{20}$, cyl. ax. 135° = $\frac{20}{50}$.

Then with the stenopæic slit at 45° accepts — $\frac{1}{60}$, and at 135° with + $\frac{1}{36}$, $V = \frac{20}{50}$ in the right eye ; and in the left eye, with the stenopæic slit at 45° with + $\frac{1}{36}$, $V = \frac{20}{50}$, and at 135° with — $\frac{1}{30}$, $V = \frac{20}{50}$. Stopping the atropine solution now after ten days, the examination was as follows :

R E, $V = \frac{20}{50}$, w. — $\frac{1}{48}$, + $\frac{1}{20}$, cyl. ax. 45° = $\frac{20}{50}$;
L E, $V = \frac{20}{200}$, w. — $\frac{1}{24}$, + $\frac{1}{14}$, cyl. ax. 135° = $\frac{20}{50}$.

Testing his near vision with this combination, I find that in looking at square objects, as a book or an envelope, it does not appear square to him ; that one side is much higher than the other. I then found, by leaving *off* the weak concave glasses and *turning* the axes of the convex cylindric so that their axes would more nearly correspond to the horizontal, that all near objects would appear to him perfectly natural. After repeated trials with the convex cylindric glasses I found that by placing over the R E + $\frac{1}{36}$, cyl. ax. 20°, and over the L E + $\frac{1}{30}$ cyl. ax. 160°, he would have perfect vision for his near point, while the distant vision remained at $\frac{20}{50}$ with the same glasses.

These glasses were then ordered for constant use. In attempting to explain the reasons why we should be compelled to change the glasses and their axes, from the result of the examination under atropine, I am inclined to think that as the patient looks downwards at an object close to his near point, he looks through the lower part

or periphery of the glass, which, in this case particularly, acts as a prism, and consequently must change the rays of light as they pass through such a complicated system of refraction as takes place in a mixed astigmatic glass.

The refraction of the two principal meridians of an astigmatic eye is quite different, for each position on the meridian of the cornea that the rays of light may strike, while the curvature in any meridian is different at its periphery. This is particularly so in the vertical meridian as the line of sight passes through the glass in looking up or down; consequently the rays of light, as they pass through in the plane of the meridian, will focus at different points.

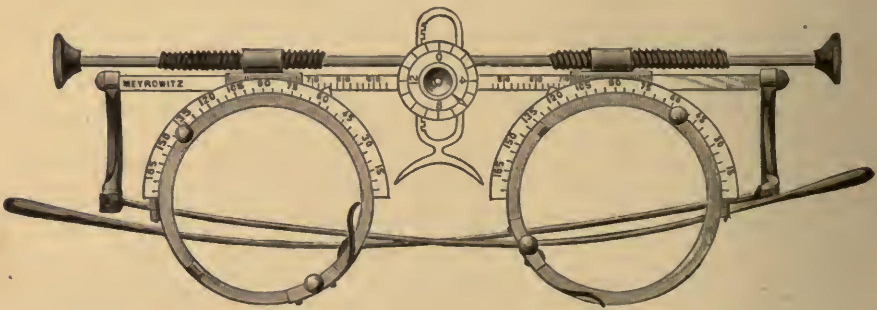


FIG. 89.—MEYROWITZ' TRIAL-FRAME FOR GLASSES.

Those passing nearest the optic axis, having less refraction than the rays passing near the periphery of the cornea, will strike the optic axis further from the corneal surface.

This condition of monochromatic aberration has been fully explained by Dr. *Swan M. Burnett*, of Washington, D. C., in a monograph on "Refraction in the Principal Meridians of a Triaxial Ellipsoid," and in his "Treatise on Astigmatism," and, I am inclined to think, is the reason why the glasses must be changed for the near point, together with the fact that in near vision the patient must look through the periphery of the correcting astigmatic glass.

You will find this condition very rare, but in all cases I would advise you to test the vision for the near point before you order astigmatic glasses, when the axes are at any other point than that of 90° or 180°, and particularly so when you find the axes of each eye the same.

Another class of cases you will meet with are those in which the condition of *anisometropia* exists—that is, a difference in the refraction of each eye—when the question arises, Shall we fit each eye separately, giving full correction for each degree of refraction existing in the examined eye? The answer to that would be, that it depends upon the degree and kind of refraction and upon the difference between the degrees. This has been partially illustrated in the case in which one of the eyes was amblyopic; but under the present class of cases, where the vision of each eye, with a suitable glass is perfect, as $\frac{20}{20}$, you must now consider the size of the retinal image, and endeavor to have the eyes work in unison. Let me illustrate this to you with the following interesting case:

CASE XIV.—Miss J. C., age 15, now at school. When studying for any length of time, as for half an hour, she has headache and "pain across the eyes," with blurring of the vision when reading music.

On examination at first, I found as follows:

$$\text{R E, V} = \tfrac{20}{70}\text{, Hm. } \tfrac{1}{36}\text{;}$$
$$\text{L E, V} = \tfrac{20}{50}\text{, Hm. } \tfrac{1}{36}\text{.}$$

She reads No. 1 Jaeger test-type at 6 inches; retinoscopy and the ophthalmoscope show mixed astigmatism.

After using atropine the result was:

$$\text{R E, V} = \tfrac{20}{200}\text{, w.} - \tfrac{1}{60} \bigcirc + \tfrac{1}{14}\text{, cyl. ax. } 80° = \tfrac{20}{50} -\text{;}$$
$$\text{L E, V} = \tfrac{20}{200}\text{, w.} - \tfrac{1}{24} \bigcirc + \tfrac{1}{9}\text{, cyl. ax. } 100° = \tfrac{20}{40} -\text{.}$$

When examined ten days after the atropine had been discontinued, the vision was:

R E, $V = \frac{20}{70}$, w. $+ \frac{1}{18}$, cyl. ax. $75° = \frac{20}{40}$;
L E, $V = \frac{20}{70}$, w. $- \frac{1}{24} \supset + \frac{1}{12}$ cyl. ax. $105° = \frac{20}{40}$.

And with this glass she can read No. 1 Jaeger test-type at from 5 to 8 inches. These glasses were ordered for constant use.

You will see that in this case each eye was fitted entirely independent of the other, and when the glasses were used vision was very satisfactory. But you will find in many cases that you cannot fit each eye perfectly, as one eye may be emmetropic, myopic, or hypermetropic, and the other different in degree or variety of refraction, even so far that one eye will be myopic and the other hypermetropic; therefore first decide what is the total degree of ametropia in each eye, and then see if they can work together with the correcting glasses.

I would advise you to follow two simple rules, as far as possible, and these are: First correct all the degrees of astigmatism that may be in each eye separately, and then add the necessary spherical glass. Second, correct the least ametropic eye, and then fit the other with a glass as near to that as will give the best vision. This rule will also apply to eyes that are not astigmatic. For instance, if you have a high degree of myopia in one and a medium or low degree in the other, you can fit the eye with the least myopia first, and then order a glass somewhat stronger, not to full correction, for the other eye.

The rule is that you should not have more than a difference of 1 D between the glasses, and I would recommend you to make repeated tests with the glasses in the trial frame, and then decide which glass will give the most comfort.

SNELLEN'S TEST-TYPES.

D = 0,5.

The Gallic tribes fell off, and sued for peace. Even the Batavians became weary of the hopeless contest, while fortune, after much capricious hovering, settled at last upon the Roman side. Had Civilis been successful, he would have been deified; but his misfortunes, at last, made him odious in spite of his heroism. But the Batavian was not a man to be crushed, nor had he lived so long in the Roman service to be outmatched in politics by the barbarous Germans. He was not to be sacrificed as a peace-offering to revengeful Rome. Watching from beyond the Rhine the progress of defection and the decay of national

D = 0,6.

enthusiasm, he determined to be beforehand with those who were now his enemies. He accepted the offer of negotiation from Cerialis. The Roman general was eager to grant a full pardon, and to re-enlist so brave a soldier in the service of the empire. A colloquy was agreed upon. The bridge across the Nabalia was broken asunder in the middle, and Cerialis and Civilis met upon the severed sides. The placid stream by which Roman enterprise had connected the waters of the Rhine with the lake of Flevo, flowed between the imperial

D = 0,8.

commander and the rebel chieftain. — Here the story abruptly terminates. The remainder of the Roman's narrative is lost, and upon that broken bridge the form of the Batavian hero disappears for ever. His name fades from history; not a syllable is known of his subsequent career; everything is buried in the profound oblivion which now steals over the scene where he was the most imposing actor. The contest of Civilis with Rome contains a

D = 1.

remarkable foreshadowing of the future conflict with Spain, through which the Batavian republic, fifteen centuries later, was to be founded. The characters, the events, the amphibious battles, desperate sieges, slippery alliances, the traits of generosity, audacity, and cruelty, the generous confidence, the broken faith, seem so closely to repeat themselves, that history appears to present the

D = 1,25.

selfsame drama played over and over again, with but a change of actors and of costume. There is more than a fanciful resemblance between Civilis and William the Silent, two heroes of ancient German stock, who had learned the arts of war and peace in the service of a foreign and haughty world-empire. Determination,

200 feet or 60m.

O

V = $\frac{20}{200}$ or $\frac{1}{10}$.

100 feet or 30m.

C F

V = $\frac{20}{100}$ or $\frac{1}{5}$.

The numbers above the letters indicate the distance, in feet and metres, at which they are seen under an angle of five minutes; those below each series of letters express the amount of vision which a patient has that can recognize such types only at a distance of twenty feet from the eye.

80 feet or 24m.

L H

$V = \frac{20}{80}$ or $\frac{1}{4}$.

60 feet or 18m.

T R

$V = \frac{20}{60}$ or $= \frac{1}{3}$.

50 feet or 15m.

E U L

$V = \frac{20}{50}$ or $\frac{2}{5}$.

40 feet or 12m.

F D T C

$V = \frac{20}{40}$ or $= \frac{1}{2}$.

30 feet or 9m.

P C D F T

$V = \frac{20}{30}$ or $\frac{2}{3}$.

20 feet or 6m.

U O F L P H E

$V = \frac{20}{20}$ or $= 1$.

INDEX.

THE END.